DESIGN AND DEVELOPMENT OF EXOSKELETON FOR THE PARTIALLY AMYOTROPHIC INDIVIDUAL

A PROJECT REPORT

submitted by

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in partial fulfilment of the requirement for the award of the Degree

of

Bachelor of Technology

in

Mechanical Engineering

GEC BARTON HILL

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Govt. Engineering College Barton Hill, Thiruvananthapuram-35

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DECLARATION

We undersigned hereby declare that the project report "Design and Development of Exoskeleton for the Partially Amyotrophic Individual", submitted for partial fulfillment of the requirements for the award of degree of Bachelor of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by us under supervision of Dr. Anish K. John. This submission represents our ideas in our own words and where ideas or words of others have been included, we have adequately and accurately cited and referenced the original sources. We also declare that we have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. We understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

Place: Thiruvananthapuram

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CERTIFICATE

This is to certify that the report entitled "**Design and Development of Exoskeleton for the Partially Amyotrophic Individual"** submitted by **Akhil Raj R., Anna Mary Jose, Bimal Sreekumar, and S. Gayathry** to the APJ Abdul Kalam Technological University in partial fulfillment of the requirements for the award of the Degree of Bachelor of Technology in Mechanical Engineering is a bonafide record of the project work carried out by them under my guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.

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ABSTRACT

On a global average, the prevalence of muscular amyotrophy is estimated to be 1 in every 3500 individuals, the cause of which may be due to a variety of reasons. This project designs and develops a body support mechanism for the partially amyotrophic individual by amplifying the movements of the leg and the feet of the physically disabled, and enabling them to walk. A detailed study of the various orthopedic diseases provided a clear insight into the various application levels of the intended exoskeleton design. A similar investigation was conducted to find the appropriate material to be used for the body of the design which is intended to meet the incumbent conditions of being light-weight, economical and durable.

The torque requirements were calculated analytically and the design constraints were simulated in Solidworks. The design of the model was finalized after studying various existing designs. The minimum muscular movement of the limb is taken as the required input for the model. NI myRIO is being used as the controller for the system. The analysis results show a maximum torque of 63.74Nm and a gear ratio of 25:12 for the motor is selected. A motor driver is used to control the speed. The peak power was observed at 85W. Aluminum alloy was chosen as the material to fabricate the system and the simulations revealed a safe and cost-effective design.

Keywords: Muscular Amyotrophy, Exoskeleton, Minimum Muscular Movement, Aluminum Alloy

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ABBREVATIONS

AI– Artificial Intelligence

BLEEX – Berkeley Lower Extremity Exoskeleton

BMI – Brain Machine Interface

CAGR – Compound Annual Growth Rate

CNC – Computerized Numerical Control

CR2 – Compact Rehabilitation Robot

DIO – Digital Input and Output

DOF- Degree of Freedom

EEG – Electro Encephalography

EMG- Electro Myograph

EXPOS- Exoskeleton for Patients and Old by the Sosang University

FNS – Functional Neuromuscular Stimulation

FSR – Force Sensitive Resistor

HAL- Hybrid Assistive Limb

IOT – Internet of Things

LEE- Lower limb Exoskeleton

LiPo – Lithium Polymer Battery

LOPES – Lower Extremity Powered Exoskeleton.

LT – Loco meter Therapy

MSP – Mini System Port

MXP- myRIO Expansion Port

NI – National Instruments

RGO – Reciprocating Gait Orthosis

SEA – Series Elastic Actuator

SCI – Spinal Cord Injuries

VCHM – Variable Constraint Hip Mechanism

VR – Virtual Reality

WHCH - WheelChair

WSE – Walking Supporting Exoskeleton

NOTATIONS

M_1= Mass of the actuator at hip joint in kg

M_2= Mass of the thigh in kg

M_3= Mass of the actuator at the knee joint in kg

M_4= Mass of the shank in kg

M_5= Mass of the actuator at the ankle joint in kg

M_6= Mass of the foot in kg

ML_1= Mass of the thigh link in kg

ML_2= Mass of the shank link in kg

ML_3= Mass of the ankle link in kg

L_1= Length of thigh in m

L_2= Length of shank in m

L_3= Length of foot in m

T_1= Torque required at the hip in Nm

T_2= Torque required at the knee in Nm

T_3= Torque required at the ankle in Nm

θ= Joint angle in degrees

g= Acceleration due to gravity in m/s^2

CHAPTER 1

INTRODUCTION

1.1 LOCOMOTION AND MOVEMENT IN HUMANS

Every living organism on this earth has a set of characteristics that help contribute to its existence and sustainability in its habitat. An important characteristic of these organisms is called movement. It is the act of changing the position or place by the whole body or any of its parts. The study of movements is termed as Kinesiology (Greek kinein:to move, and logos: to study). The movement of limbs and appendages assists in locomotion and in changing the body posture in order that equilibrium is maintained against gravity.

Locomotion is the term given to the movement when the organism or person moves as a whole, thereby achieving a change of place and the organisms with this ability are classified as motile organisms. This is possible in vertebrates like humans because of the bones or endoskeleton, and the contraction and relaxation of muscles that are attached to them, according to the required need. The bones serve as levers and the motion of the skeletal muscles move them at the joints. Voluntary control by the central nervous system is exhibited in the whole process [1].

1.2 MUSCULAR AMYOTROPHY AND PARESIS

Muscular Amyotrophy is the medical term given to the phenomenon of progressive muscular tissue wasting in human beings. It is a neuropathic disorder associated commonly with middle to older aged individuals. It may be Diabetic Lumbosacral Plexus Neuropathy (also known as Bruns-Garland syndrome), or neuralgic amyotrophy [2]. In Diabetic Lumbosacral Plexus Neuropathy, patients are typically observed to have an asymmetric, painful muscle wasting and weakness affecting the lower limbs and progressive loss of reflexes and objective weakness on examination. Patients may describe a sudden onset of sharp pain in the hip and thigh that can spread to the opposite side over weeks to months, generally in a stepwise and steady progression affecting both proximal and distal muscles [3]. Classically it occurs in older type 2 diabetics, and in severe cases it leads to severe leg pain and paresis. The following figure, Figure 1.1, shows the musculoskeletal system of the human body.

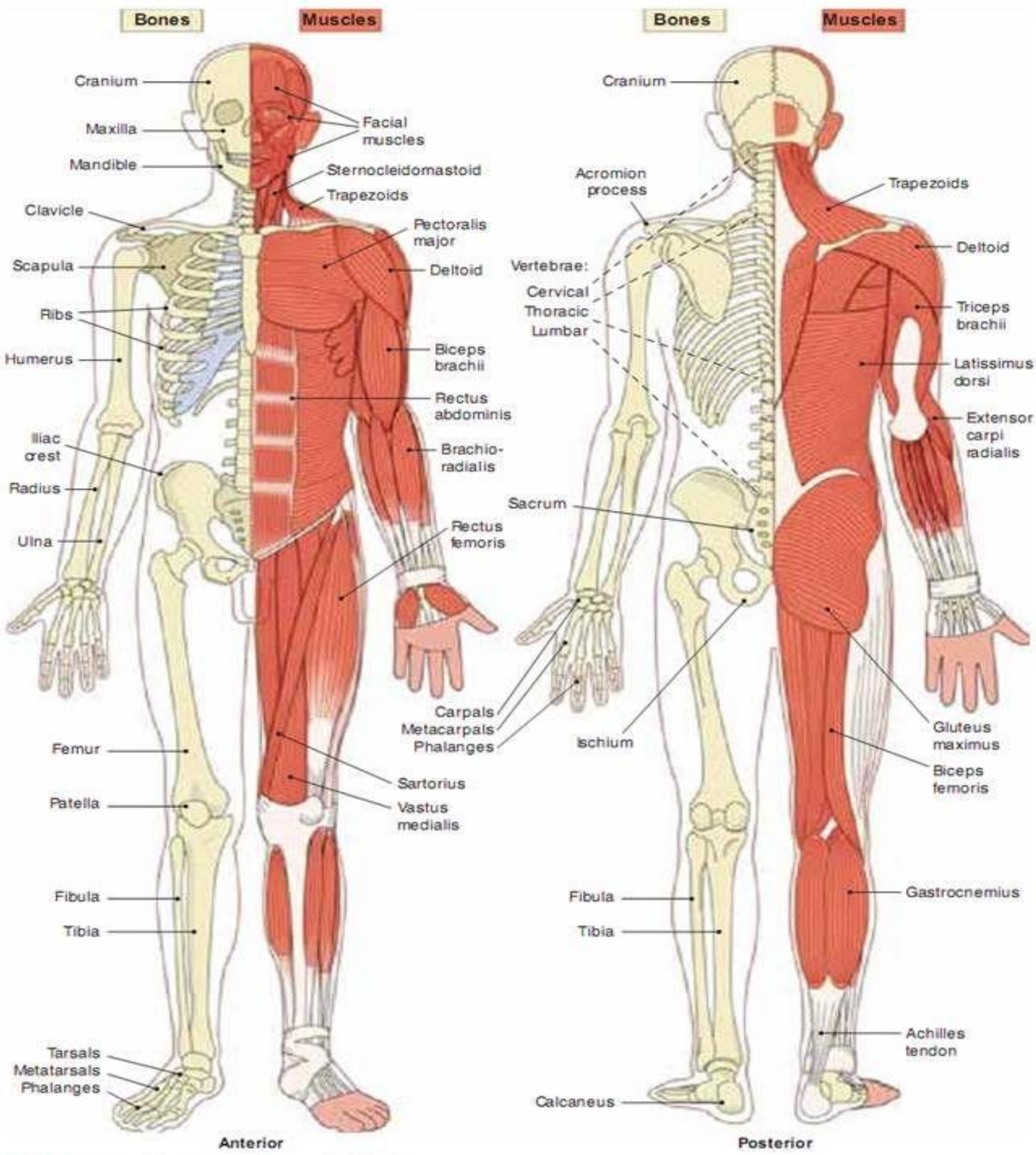

Fig 1.1: The Musculoskeletal system

Paresis is the name given to the condition where muscular movement is weakened. Paralysis, however refers to the complete loss of the ability to move the whole body or any of its parts, owing to neuropathic reasons. Unlike paralysis, individuals with paresis still have some control over the affected muscles. They have restricted movement in the muscles. Therefore, it is also called partial paralysis.

1.3 TREATMENT

The reason for the appearance of this disorder may be ischemia (A deficiency of blood in a tissue that is caused by constriction or obstruction of local blood vessels and results in a reduced supply of oxygen to the tissue), induced by a metabolically induced focal microvasculitis(a range of diseases and presentations linked with a disease, wherein an inflammation of small blood vessels is observed). Treatment consists of adequate analgesia(painkillers) and rehabilitation [4].

Treatment for paresis includes the following in addition to the prescribed medications:

- Physical Rehabilitation: It involves the utilization of techniques such as exercise, massage, etc. and thus improve mobility, flexibility, range of motion and stimulating one's nerves and muscles in the process
- Occupational Therapy: This includes strategies that can be employed for carrying out daily activities easily when one is a victim to paresis.
- Assistive devices: These are equipments that can help with mobility and other day to day activities. They include: Walkers, wheelchairs, grab bars, specialized handles and grips, voice activated technology.

1.4 REHABILITATION

Rehabilitation seeks to meet the objectives of helping survivors become independent and thereby attain a better quality of life. Although it does not serve as a cure to the disorder, it can substantially assist in the achievement of a better outcome in the long run.

Rehabilitation gives the individual opportunities to regain the skills that were lost as a result of paresis. These may include coordinating leg movements that helps to walk or the actions required in carrying out complex activities (figure 1.2). In addition, it also provides a means to compensate any residual disabilities. It is unanimously agreed upon by experts in the field of rehabilitation that meticulously directed, accurately focused and incessant practice- the sort of practice employed by new learners of a skill- is the key element for such programs. It also improves endurance, strength and more importantly, flexibility. Through lifetime commitment and perseverance basic skills can be relearnt.

Figure 1.2: Rehabilitation

It is advised to start rehabilitative therapy immediately after the overall condition of the patient has stabilized, preferably within the 24 to 48 hours after the previous paralysis attack. It begins with the promotion of independent movement by prompting them to alter positions as frequent as possible. They are made to engage in different types of motion exercises to empower their impaired limbs. They may be passive or active range-of-motion exercises. Nurses and therapists assist the patients to perform the complex and demanding activities such as using a toilet, dressing, etc. Thus, the first stage of the patient's return to independence is represented with the hint of his abilities returning back to him. However, it could take months or even years for the patient to be able to properly maintain and refine these skills.

1.5 INSPIRATION FROM NATURE

Following the footsteps of Issac Newton, who had once said, "Look deep into nature, and you will understand everything.", scientists have been able to propose solutions to existing problems by mimicking the processes in nature. Such systems, devices, substances or man-made processes which imitate nature is highlighted by the word Biomimetics and the science and art of building and designing such biomimetic structures is termed as Biomimicry. Research in this field is wide and often finds itself entangled with the realms of medicine, military, robotics, nanotechnology and Artificial Intelligence (AI). The following figure (Fig 1.3), shows the example of

Figure 1.3: Inspiration from nature

Neural Networks are examples of biomimetic system which works very much like the nervous systems in animals. It makes associations, assumptions, and predictions that not only helps it to identify objects and features, but also to learn from its errors. Another example of such a system is an android system which is a humanoid bot, made to replicate both the form and abilities of human beings.

These processes and systems have, provided effective solutions for existing difficulties prominent in society and also made lives easier in the process while improving the quality of living. Exoskeletons are thus a biomimetic system in the manner in which it associates itself in the process of exhibition of motion of the human body. It primarily seeks to assist in the kinetic motion of different parts of the body without offering obstruction or hindrance to the other functional aspects that are involved.

1.6 EXOSKELETONS

Exoskeleton is the term given to the external skeleton which offers protection and support to an animal's body. They consist of certain specialized rigid and resistant parts that satisfy a set of functions like feeding, support, protection, etc. It is therefore, an incumbent part of the human body.

The powered exoskeleton which also goes by the names: powered armor, exosuit, exoframe and hard-suit; is a mobile machine that's wearable and powered by an actuator system (which may be pneumatics, hydraulics or motors) which serves in the movement of the limbs, their increased strength, and endurance. The first device that resembled an exoskeleton to be made was developed by Nicholas Yagn, a Russian, in 1890 [5]. It was an apparatus that ran on stored energy in compressed gas bags to achieve the functions of walking, running and jumping. It was, however, a passive device and therefore demanded human power. In 1917, Leslie C. Kelley, a US inventor, designed a device that worked on steam power. It had artificial ligaments which acted in accordance with the movements of the wearer [6]. He named it the pedomotor and the major advantage of this model was the fact that energy was generated separately.

It was much later, in the 1960's to be exact, that the first true exoskeleton design with a promising potential came into existence. It was the combined effort of both General Electric and the US Military that lead to its development. It was hydraulically powered and was able to amplify the user's strength by 25 times. With the identification of the fact that the ability of soldiers can significantly push greater limits due to the use of such models, newer and improved versions of this existing model was proposed. These were expected to achieve better results while being controlled by on board computers. Potential application of fuel cells, batteries, IC engines, etc. as a power source were also considered.

Soon it was realized that they could become useful in medical care as well. The impending shortage of staff and the ever-increasing number of patients, several Japanese engineers developed exoskeletons to assist the nurses in lifting and carrying these patients (Figure 1.4) They were also employed as Step Rehabilitation Robots in order to help the patients undergoing rehabilitation. Moreover, it also finds application in firefighting, construction, ship-building and to improve precision in surgery.

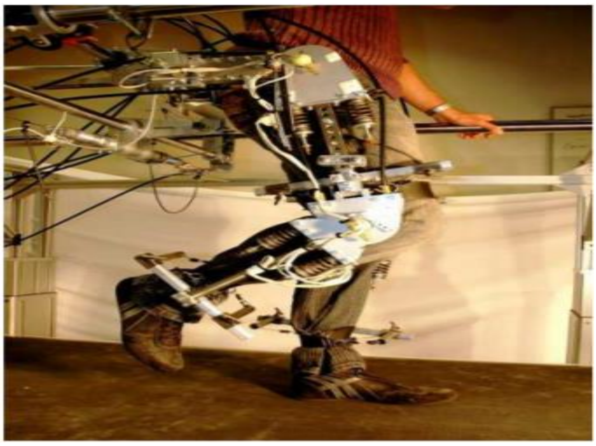

Figure 1.4: LOPES- A Powered Exoskeleton

Examples for the exoskeleton models that have been unveiled and found utility in different fields of application are (i) Berkeley Lower Extremity Exoskeleton or BLEEX , (ii) Lower

Extremity Powered Exoskeleton (LOPES), (iii) Bionic arms , (iv) Hybrid Assistive Limb (HAL)

1.7 OUTLINE OF THE THESIS

The thesis is structured in the following manner. The first chapter introduces not only the importance of movement and locomotion in humans, but also discusses about a disorder that is studied and the varied solutions that exist. It briefly gives an idea about the adoption of the biomimetic exoskeletons as a solution. The second chapter correspond to the background and prior work. Here, actuator mechanisms that have been commonly used in the previous systems are also defined along with the detailed study of material properties in order to choose the material for the proposed design. Relevant commercially available exoskeletons and their technological advancements are brought to notice.

The third chapter gives a clear picture on the gait theory, calculation of torque required at different regions, and the basic methodology of the design. The fourth chapter describes about the different designs that were chosen The salient features of each design is separately mentioned. In the fifth chapter, the essential hardware components required to actuate the proposed system is discussed. A detailed description of the motor, its elements and the controller is given.

The sixth chapter elaborates upon the various evaluation criteria that the design must meet so that it meaningfully fulfills its incumbent objectives, including the cost constraints. The discussion of results of various analysis conducted is presented in the seventh chapter. The plots of the obtained data are presented as well. The eighth chapter discusses the conclusions that are drawn from the entire design process. Finally, the possible future work that can improve the model is discussed.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL BACKGROUND

Universally, the numbers corresponding to the disorders affecting muscles that inadvertently or subsequently lead to depreciated muscular activity and underutilization or even total unemployment of the limbs in the common man is very well above the mean values. As more and more individuals become older, they become susceptible to a wider range of diseases both on the basis of lifestyle and in terms of innate health conditions often pertaining to disorders. The occurrence of muscular amyotrophy, for example, is estimated to be seen in one in every 3500 individuals, which is a very gruesome number as such. Due to the high carrier frequency, the burden of this genetic disorder is very heavy in developing countries like India. The various other disorders that come under this category are also around the same number.

2.2 EARLIER REVIEWS

A detailed study regarding the motion in human beings is essential in order to understand the ways in which each part of the lower limb moves and the position they take in each part of the motion. A number of articles regarding the different instances of motion were referred upon in order to get an accurate review of how motion takes place and how it propagates.

In an analysis conducted by A. Kralj et al., the process of sitting down and standing up was studied [7]. This was based on the fact that both of these are necessary functions and prerequisites for the normal locomotion in humans using their limbs. They also assist in the maintenance of proper bone loading, offering skin pressure relief and the prevention of excessive demineralization in bones. The study was conducted on 20 normal subjects who had no known history of orthopedic or neurological problems and the determined events were chosen primarily based on the changes in ground reaction forces. From the analysis of the data collected in the study, it was clearly indicated that the process of standing up was accomplished 1.3s faster than the process of sitting down. It was noted that during each phase, a specified activity occurs, with the required activation of effectors (the muscles).

Orthotics is the term given to the medical specialty which deals with the design and application of orthoses (externally worn devices that alter both the structural and functional characteristics of the skeletal system and the neuromuscular system). An orthotist is a primary medical head responsible for prescribing, and managing of orthoses. An orthosis is used to guide, limit and/or immobilize a body segment for specific reasons and also control and restrict movement in the required direction.

The reciprocating gait orthosis or RGO, is one among the different orthoses designed to help regain stance and walking in paraplegic patients. It was observed that the great expenditure of energy while employing orthotic aids for walking was obstructing the effectiveness of the same, consequentially leading to slower mobility, thereby limiting its utility to indoors. A complete evaluation of biomechanical nature was conducted on RGO locomotion in order to improve the accomplished effects of the same [8]. It was concluded that the power for the RGO must be driven from elsewhere in order to terminate the above said condition and to achieve real mobility. It was also pointed out that paraplegic training was required before the RGO's were made to use and that cardiovascular conditioning of the user must be maintained.

The performance of orthoses and exoskeletons were limited by a large number of factors. The weight of the powered devices encumbered the wearers movements by making them difficult to augment. The devices that have been designed were unnatural in shape and noisy as well. It was found that a lack of direct transference and exchange of information between the wearer's nervous system and the device also greatly affected the dynamics of the system [9].

Perhaps, one of the most challenging issue is the variability and uncertainty that pertains to the biomechanics corresponding to the human body and the chosen exosuit [10]. It is incumbent to formally test out and experiment on how the body interacts with the different solutions and learn more on the human-robot interaction.

Close cognition and interaction with the user being a characteristic feature of the exoskeleton, the necessity of cognitive interactions is strict [11]. Further research activities will certainly seek a robust solution of interfaces by neuromotor control structure. Hybrid technologies employing both exoskeletons and motor neuroprostheses will be a definitive structure. However, such systems will impose financial constrain on the users.

2.3 POWERING THE EXOSKELETON

The actuator systems or drives as they are commonly called, act like muscles when the links and joints of the exoskeleton act as supporting skeletal system [12]. These power the system to act and perform the functions required of them. These rotate or move the appendages(links) in order to alter the configuration and thereby achieve different positions. They must possess enough power to alter the acceleration and offer retardation in the links. They must be able to carry loads while being light in weight themselves. They should also be reliable, easy to maintain, economical, properly responsive and accurate as well. In addition to all this, they should be able to operate in high DOF's, withstand high pressure, offer a wide velocity range and low inertia.

There are different types of drives that are commonly used and they are:

- Pneumatic Actuators
- Hydraulic Actuators
- Electrical Drives
- Mechanical Systems

2.3.1. PNEUMATIC DRIVES

Pneumatic actuators convert energy of compressed air into mechanical motion. The eventual effect of motion may be rotary or linear. A few types of pneumatic actuators are tie rod cylinders, rotary actuators, rotary cylinders, grippers, actuators combining the rotary and linear motion, rodless actuators with magnetic linkages or mechanical linkages, vacuum generators, etc.

The common components of a pneumatic actuator are pistons, cylinders, valves, and even ports. Pistons are normally covered by a seal or a diaphragm to keep the upper portion of the cylinder air-tight. Depending on the type of required action, the spot for input varies and the output pressure is directly proportional to the size of the piston. The air is stored in a reservoir and a series of pipes carries it to the cylinder. The pressure in the cylinder is transferred to the valve system. The following figure, Figure 2.1, shows the schematic diagram of a pneumatic actuator.

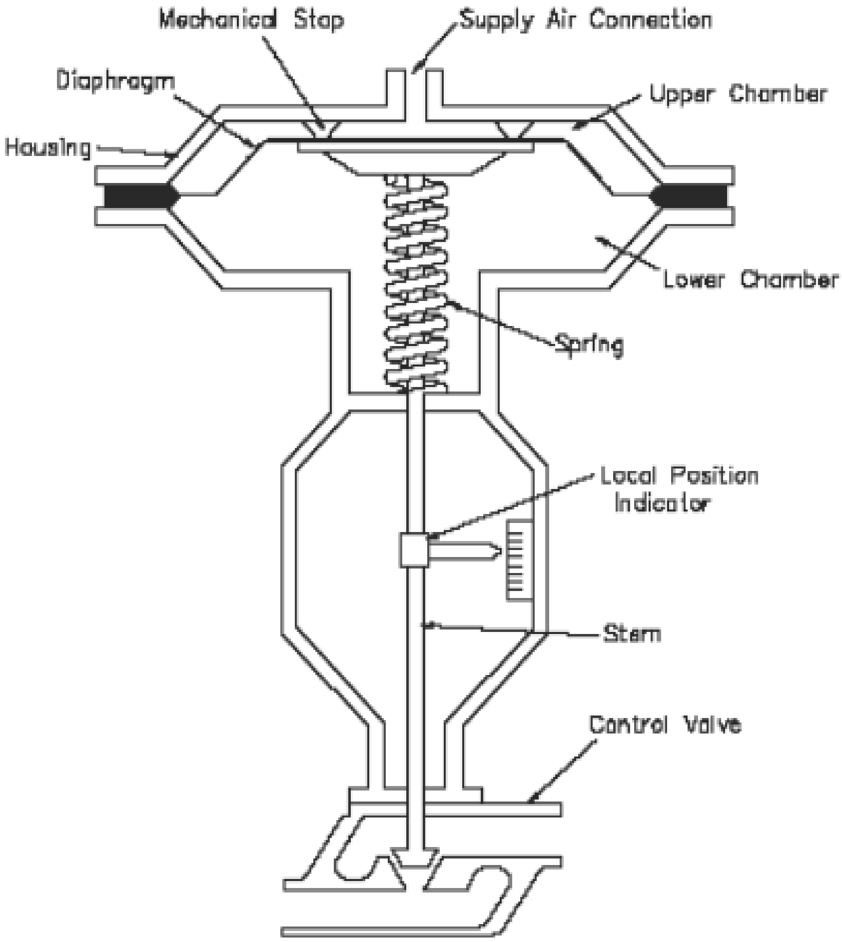

Figure 2.1: Schematic diagram of a pneumatic actuator

This pressure at the valve is the signal of control and a pressure transmitter is used to monitor the pressure in the vessel and transmit the signal. This output from the transmitter is fed to the valve which then adjusts itself to close or open accordingly and decrease the flow or increase the flow respectively. The outflow takes the excess pressure away with it. This process is referred to as a direct acting process.

2.3.2. HYDRAULIC DRIVES

Hydraulic actuators are similar in design to pneumatic actuators; however, they use a fluid of known viscosity instead of compressed air. The most commonly used fluids are oil and water. These use the power of the fluid to facilitate the mechanical operation. The output may be linear, rotary or oscillatory in nature. Liquids are nearly impossible to compress, and therefore a large force can be exerted by the actuator. A hydraulic actuator is shown in figure 2.2.

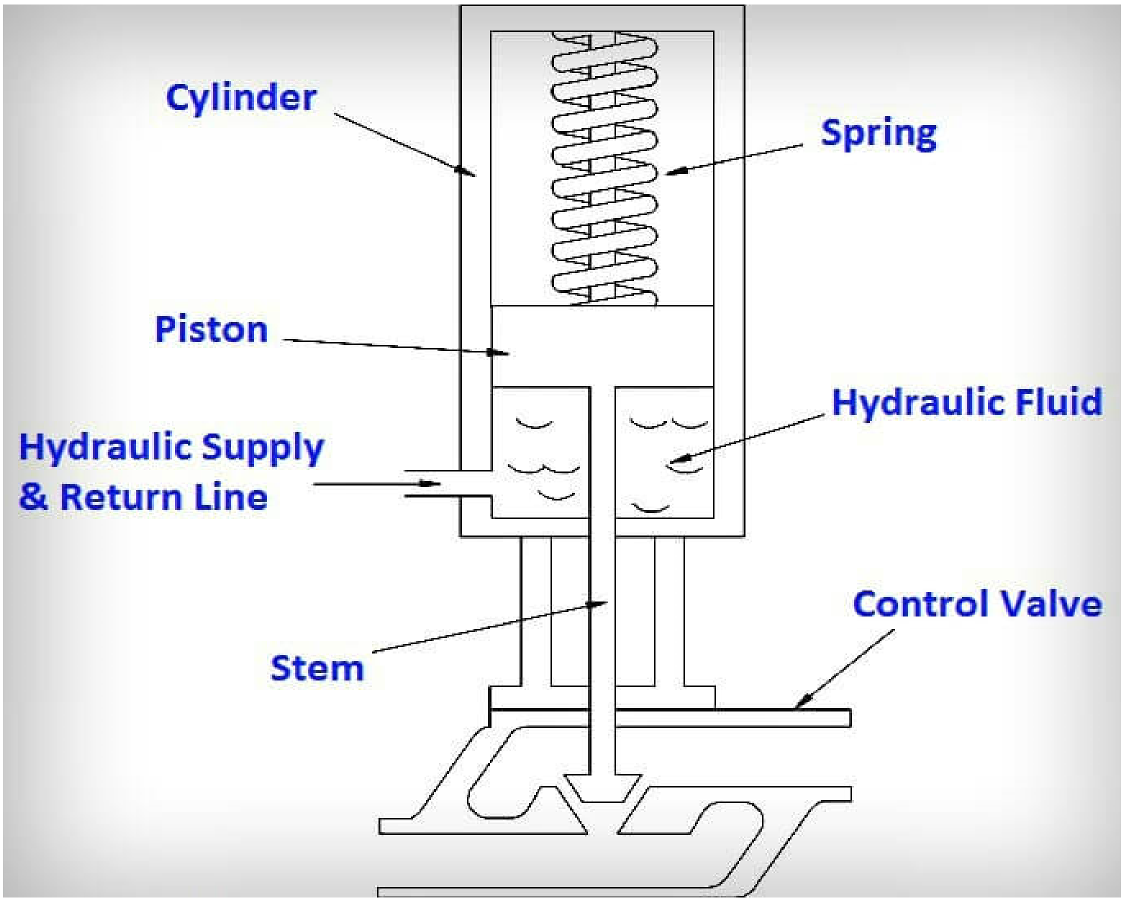

Figure 2.2 Diagram of a hydraulic actuator

Hydraulic cylinders are basically of two types. It may be called single acting when the fluid pressure is applied to exactly one side of the piston. A spring is used in this case for the return stroke. Similarly, it is called double acting when pressure can be applied to both sides of the piston and the differential pressure between the two sides helps it to move from one side to the other and back.

In this type of system, the working fluid enters the control system from a pressure line, via the stationary throttles and is then taken to the variable throttles and then actuator chambers. A gate slide is present and in order to control its position, an input signal is passed through an EM converter. This provides a change in displacement which in turn contributes to the change in the clearance values between nozzles and gate slide. Consequentially, the slide valves get displaced due to the change in pressures in the actuator chambers.

It is observed that the mechanical advantage of a hydraulic actuator often surpasses 100,000. When provided with necessary feedback mechanisms, the power amplification can be properly controlled and thus substantially improve both static and dynamic characteristics and further the efficiency of the control systems.

2.3.3. ELECTRICAL ACTUATORS

Electric drive is the term given to the actuator system or motor that drives a set of links, through a mechanical transmission so that they may perform a specific function. In the beginning hydraulic robots were more common, but with recent improvements in motor design and development, the utilization of motors to drive the robot became a popular trend. The fundamental drive element for an electric motor was much lighter than that for hydraulic power.

It was observed that the repeatability and accuracy of these robots were much better when compared to their fluid powered counterparts, in terms of cost. They involve higher power conversion efficiency and can be easily maintained or repaired. They may be either servo motors or electric linear actuators. The figure (Figure 2.3), given below shows different types of electric actuators.

Figure 2.3: Electric actuators

Servomotors are used wherever closed loop control system is required. They consist of a motor coupled to a sensor which provides the necessary position feedback. They also require a sophisticated controller. They find application in CNC machines, robots and automated manufacturing. An analog or digital signal serves as the input and it represents the position that is commanded for the output shaft. An encoder is paired with it and it provides position and speed feedback. Upon comparing the feedback with the input, if there is any difference from the required value, a signal indicating error is generated. This makes the motor rotate in either direction, thereby bringing the shaft to the required position. As the position is approached, the signal becomes zero bringing the motor to a halt.

An electric linear actuator is typically a motor connected so that a lead screw can rotate. The helical threads of the lead screw mesh with the helical threads of a lead nut, preventing the nut from rotating with the lead screw. By connecting suitable linkages to the nut, linear displacement can be achieved. There are different motors which are used for such systems, like the dc brushless motor, stepper motor and even induction motors. Depending on the requirement and load conditions, these motors are chosen to help achieve motion.

2.4 DEVELOPMENT OF SERIES ELASTIC ACTUATOR

A Series Elastic Actuator (refer Fig. 2.4) is an electromechanical actuator which has linear springs that are intentionally placed in series in between both motor and actuator output [13]. A linear actuator model of second order was investigated in order to develop the design. The spring offers efficient force control and high fidelity despite employing a transmission to achieve the desired high force to mass and power to mass ratios. The choice of a spring constant was eventually compromised to a value between the both extremes.

Figure 2.4: Series Elastic Actuator

The series elastic actuators were further modified using a novel, monolithic and compact torsional spring [14]. The spring that was exclusively for rotary SEA's, had an external diameter of 85mm, a thickness of 3mm, and a weight of 61.5g. It is able to withstand torque values upto 7.68Nm and possessed a stiffness of 98Nm/rad. The simulated data in FEA based optimization process managed to have agreeable with the experimented data. Parallel connection of the same spring, provided more torque as it split the whole torque between the elastic modules. The fatigue analysis did not assure a perpetual fatigue life of the spring, since the estimated fatigue limit (0.79GPa) is seen to be just below the calculated value of maximum von Mises stress (0.84GPa).

2.5 MATERIAL STUDY

A review of various material alternatives that could be used to build exoskeletons were considered. Of these, steel, aluminum alloy and carbon fiber were suitable choices. A detailed study was conducted on each material to find out if their properties would suit the need.

2.5.1. STEEL

Steel is the alloy of iron, carbon, and other elements, with a greater carbon composition and commonly used in construction and other such applications, owing to its high tensile strength and lower cost [15]. It is normally made through any of these two methods: Electric arc furnace method or Integrated method. The former uses scrap iron as the principal input. It is preferred due to the ease of the method and it being faster. The latter employs raw materials in addition to scrap in order to create steel.

The mechanical properties of steel are attributed to it via the combination of the materials used to prepare it, the type of heat treatment and the nature of manufacturing process. Although it mainly constitutes of iron, the addition of other metals and non-metals can improve its properties drastically. For example, the addition of manganese, niobium, etc can improve the strength of the steel formed. However, it may also have an adverse effect on properties such as ductility, weldability, etc. Figure 2.5 shows the stress-strain curve of Carbon steel and Stainless steel.

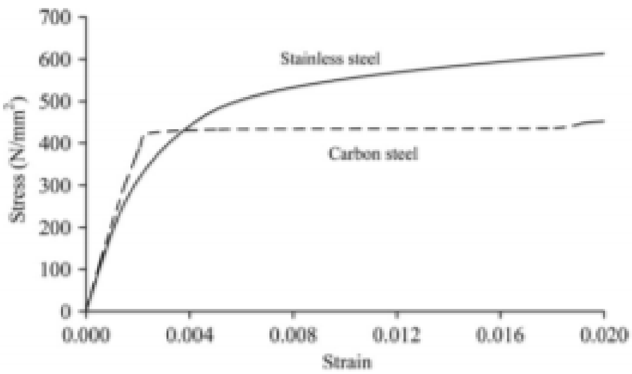

Figure 2.5: Stress vs strain curve of carbon steel and stainless steel

Steel being strong and durable, is a good material for forming the structure of the exoskeleton. It can withstand the high tensile, compressive and shear forces. It also doesn't warp under heavy loading. It is also eco-friendly and structurally stable. But it possesses certain disadvantages as well. If not maintained properly it will corrode and the cost for maintenance might present itself as an obstacle. Furthermore, it is also a heavy material compared to the other two alternatives.

2.5.2 ALUMINIUM ALLOYS

Aluminium is the third most common element and the world's most abundant metal. It is the most widely used material, right after steel owing to its versatility. Not only soft, ductile and corrosion resistant, pure aluminium is a good conductor of electricity [16]. Alloying with other elements is a key to unlocking enhanced properties in aluminium. The formability curve of Aluminum is compared with that of steel in figure 2.6. It being one among the lightest metals, it has a superior strength to weight ratio when compared to steel.

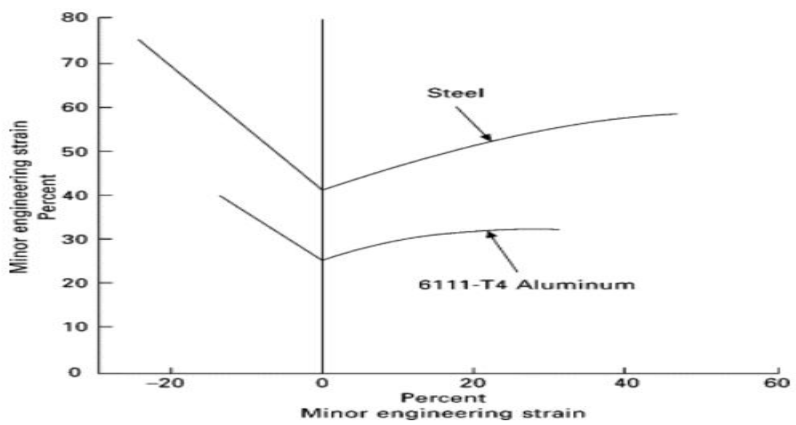

Figure 2.6: Formability curves of steel and aluminum

Aluminum has a low density (2.7 g/cm^3 for aluminium alloys compared with 7.87 g/cm^3 for steels). This makes it a suitable material to design the skeleton of an exoskeleton. Furthermore, it is corrosion resistant as well as being able to be cast to high tolerance values.

2.5.3 CARBON FIBRES

Carbon fibers (Fig 2.7) are fibers of about 5-10 micrometers in diameter [17]. They are composed of carbon atoms. They are also known as graphite fibres. They have several advantages: high values of tensile strength, stiffness, chemical resistance, temperature tolerance and low values of thermal expansion and weight. But they are quite expensive when compared to the other alternatives.

Figure 2.7: Carbon Fibers

A carbon fibre is made from carbon atoms bonded together in crystal alignment. this gives the fibre the high strength/volume ratio. They can be combined with plastic resins to form a reinforced polymer which has even great strength to weight ratio.

2.6 THE CONTROLLER

The controller is the brain of the device. It gives signals and commands for the rest of the body to perform a certain set of functions. There are two major systems by which control is achieved. They are the open loop control system and the closed loop control system [18]. The difference between the two is that the latter utilizes the feedback from the recipients and continuously refines the control based on the result of the comparison of this feedback with a respective benchmark value. The former follows a specified pattern and does not involve the generation of any feedback. Control systems are therefore an incumbent part in order to maintain and guide the flow of control within robotic devices.

The NI myRIO 1900 is one such device that is embedded and reconfigurable. It is a real-time evaluation board developed by National Instruments. It runs on LabVIEW [19]. It was found to be a suitable option as a controller for the exoskeleton model.

2.7 INITIAL STUDY ON ADAPTATION TO ASSISTED-WALKING

During earlier studies, as mentioned before, it was clearly identified that the locomotion of individuals using assisted walking mechanisms acquired high energy expenditure from the user's part. The functional neuromuscular stimulation or FNS in short, on energy expense in the process of orthosis associated ambulation was looked into [20]. This also aimed to look into the future of predicting a selection criterion for the type of orthosis preferred for the compliant patient. It was found that as a direct consequence of hemodynamic effects, locomotion could be improved through electrical simulation, but this did not increase the energy expense nor could it predict the above requirement. It was decided that an ergometric wheelchair (WHCH) test would help predict the tolerability and the cardiorespiratory system's efficiency, for each subject.

2.8 DETECTION OF MUSCULAR FORCE

The first and foremost requirement in order to facilitate measurement and automatic controls is the primary sensing element or the sensor. A sensor senses the state, value or condition of the process variable and gives an output that reflects the same. It is then transformed from one form of energy to another using transducers to operate the concerned control device [12]. There are many types of sensors and their classification varies upon the factors it is based on. Force sensors, capacitive sensors, encoders, light sensors, etc, are commonly used sensors.

In the conventional systems, tactile pressure sensors, torque sensors and EMG sensors are employed to detect human motion intention [21]. A sensor suit was made out of ultrasonic sensors for a study to find out how effectively they can detect the muscular force. It was proved to be an effective choice; still the components were costly and a slight variation in the environment could affect the sensing process.

2.9 THE ROBOKNEE

The RoboKnee is a one degree of freedom exoskeleton that meant to achieve a high level of transparency [22]. Here the user's intent is detected from the knee joint angle and the ground reaction. It provides the energy required by the user to carry out the locomotory function while keeping himself in control.

Series Elastic Actuators were used to attain low impedance. It proved to be a feasible model that enhanced strength, speed and endurance. The wearers themselves felt as though they had grown new muscles. Nevertheless, the system is too bulky and has a short lifetime between the recharge sessions.

2.10 DESIGN OF BLEEX

The Berkeley lower Extremity Exoskeleton was a design proposed at UC Berkeley [23]. The figure 2.8 shows the BLEEX exoskeleton. It was designed to assist in manual labor and to transport materials to areas that cannot be accessed by vehicles [24]. It was a system with 7 degrees of freedom with four of them actuated. The data from the Clinical gait analysis became the framework for this design. It was found that the newly recorded data showed sufficient disinclination to the original CGA curves, indicating that the kinematics and dynamics of the new system did not wholly match that of humans. Anyhow, it was finally observed that BLEEX was able to support a weight of up to 75kg, walk to speeds of 1.3m/s and perform numerous maneuvers without previously being programmed or human sensing.

Figure 2.8: BLEEX

BLEEX became the first human exoskeleton to succeed in the demonstration of walking energetically autonomous, simultaneously supporting both its weight and the payload. The original design was actuated using hydraulic systems. An experiment on the application of electric motors and gearing for powering the joints of the exoskeleton was performed [25]. Based on the derived motor torque v/s speed characteristic curves, and the capabilities offered by the motors, the proper motor size was determined. Clinical gait analysis data was also considered in the determination of the required curves.

Finally, a full-fletched power analysis was also conducted to find out the type of inefficiencies that encumbered actuation selection. The scheme to introduce electric actuation in exoskeletons was proven to be twice as effective, efficient and heavy as the previously used hydraulic actuation.

2.11 DEVELOPMENT OF LEE

A wearable lower limb exoskeleton (LEE) was developed to carry out research on enhancement and augmenting the human walking and load carrying abilities. Here human intellect is utilized as the control system so that the device can be manipulated. It is anthropomorphic in nature and shows considerable adaptability with regard to its previous alternatives [26]. It sought to relieve the physical fatigue which was a consequence of excessive walking or the payload being heavy.

2.12 PERFORMANCE EVALUATION OF GRAVITY BALANCING ORTHOSIS

A hybrid method was made use of to accomplish gravity balancing of patients with hemiplegia. It hoped to eliminate the negative effects of gravity on the design. The prototype was fabricated in aluminum and the center of mass of the system and user as a whole was initially found out. Springs enabled to balance the system properly. The EMG (electromyographic) data of the muscles that are involved in the motion were assembled and reviewed.

This study was effectively conducted on five normal individuals and a subject who was victim to right hemiparesis. It was seen that during the static experiment, the EMG values of the state without the device being attached to the user was four times that of its value when the device was attached to the individual [27]. While the walking experiment proved that only the hip joint torques were refined due to gravity balancing, in the healthy individuals; it improved the range of movements at the knee and hip joints positively.

2.13 DESIGN OF EXPOS

EXPOS is a wearable exoskeleton designed specifically for the use of elderly people and patients [28]. It is tendon driven and intended to meet the limitation of the weight factor. It has a caster walker which carries the heavy items such as the battery, controller, driver and motor thereby minimizing the constraints of weight and volume. It achieved the functions of walking, sitting down, and standing up, fairly by means of the pulleys at the hip and knee and the motors that connected the tendons. It was able to arrive at the power requirement of each individual user.

2.14 THE CYBERNICS APPROACH

Over the course of time interdisciplinary research centered on the various aspects of science, social science, engineering, technology, ergonomics, physiology, law, ethics, economics and management, etc. began to develop. This new domain of research is referred to as Cybernics. Hybrid Assistive Limbs (HAL) systems using the fundamentals of Cybernics was reviewed. Robot Suit HAL is actually a cyborg type robot which can expand, support physical capability and augment [29].

This offered two different types of control systems, the Cybernic Voluntary Control System and the Cybernic Autonomous Control System. The effectiveness of the application and the result of the autonomous control system was presented quite positively. With this future scope of the application seemed to be prospect. Figure 2.9 shows HAL-5.

Figure 2.9: HAL-5 Exoskeleton carrying a weight.

2.15 THE MOTOR-POWERED GAIT ORTHOSIS SYSTEM

In orthotic gait, considerable amount of effort and high energy consumption are the major drawbacks encumbering its effectiveness [30]. An investigation into the effects of external actuators on assisting the orthotic gait of patients suffering from spinal cord injury was done on five male subjects. Two types of linear actuators using DC motors were developed in order to assist the knee and hip joint of gait orthosis. They offered two degrees of freedom and expansion patterns in paralysed muscles was observed.

2.16 A PSYCHOLOGISTS PERSPECTIVE

It was found that through presenting collaboration between psychologists and the robotic engineers would improve the rate of advancements in both fields. This would mean that there could be sufficient insight into the psychological aspect of the subject who wears an exoskeleton and thus refine the existing calibre of the systems. A number of biomimetic alterations were proposed to meet an economic locomotive stand [31].These suggestions include the utility of elastic mechanisms to counter the difficulty in achieving proper positive and negative work, employment of biarticular linkages to transfer energy, powering push-off at ankle and thereby reduce collision costs, taking care to avoid disruptions of the passive pendular dynamics in specific phases of gait, etc. With such necessary precautions and changes, a proper exoskeletal design with minimal metabolic cost could be designed.

2.17 THE EXOSKELETON WALKER

A patent application containing the novel design for a powered exoskeleton walker which was self-contained, was studied [32]. The walker was intended to support the mobility impaired individual while making them move through a set of definitive movements that correlate to the normal walking motion. It included a battery pack or power pack along with the power cables, the exoskeleton with actuators, and the control system. However, the design was much too complex, was heavy and included a lot of parts.

2.18 EVALUATION OF A NOVEL HIP CONSTRAINT ORTHOSIS

The effects of an isocentric RGO with variable constraint hip mechanism (VCHM) on kinetics and kinematics of gait was looked into [33]. Normal subjects were tested with both systems and the hip reciprocating mechanism uncoupled and coupled. Walking performance was compared in both cases. The energy expense that arose in the muscles as a result of the motion was reduced and that a longer distance could be covered.

2.19 DESIGN OF MINA

An overground robotic device, MINA(Fig 2.10) is worn on the back and wraps itself around the legs so as to provide assistance in terms of mobility for subjects who suffer from paraplegia or paresis [34]. The knee and hip joints are powered using compliant actuation. Forearm crutches helped provide the necessary balance. Within a few hours of practice, it was observed that MINA helped provide for walking speeds of 0.20m/s. It was also confirmed that in the process of using the device, the user did not feel weary or need great cognitive effort. This proved that some amount of training was required regardless of whichever device used in order to achieve the proper utility of the device.

Figure 2.10: MINA

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2.20 DESIGN OF REWALK

The design and control of the low-weight, patient-tailored robotic orthosis for patients with SCI , the ReWalk was assessed in order to substantiate its claim of being safe and enabling them to perform their routine ambulatory functions properly [35]. The device was fully equipped with a knee actuation system which consisted of an electric motor, an inertial measurement unit and also a Harmonic drive gearbox, contained within a backpack.

The backpack held the battery, motor drivers and a blackboard as well. Motion analysis at the kinematic level proved that the subjects were able to walk faster, in a balanced and stable manner. However, a high degree of performance variability has been identified and it was reported to be due to the level of spinal injury received by the patient. The other factors that affected the said variability have not been identified.

2.21 MOTORISED EXOSKELETON BASED ON CGA PATTERN CONTROL

A novel design of using a spring system to store the energy at peak torques at each joint, based on the biomechanical analysis of the lower limb was explored. The exoskeleton model chosen for the study possessed 9 degrees of freedom from hip to ankle [36]. The control algorithm with which control of the exoskeleton was maintained, was based on Clinical gait analysis and is called Patternized Control Approach. It was concluded from the demonstration and the results that the model performed assisting the walking steps smoothly in accordance with the pattern of the gait cycle; but latency of response time still remained.

2.22 ENGINEERING THE SOFT EXOSUIT

Soft robotics is a new subfield of robotics that combine the utility of active soft materials with contemporary robotic designs and control principles. The world’s first engineered soft exosuit, that greatly depreciated the inertia and mechanical impedance, when compared to the previous designs and models that were developed, possessed pneumatic actuators to assist the knee, hip and ankle [37]. By virtue of this system, the symbiotic human-machine interaction is made possible with the low weight and the compliance of device. Through the virtual anchor technique, wherein a network of inextensible, soft webbing attaches the actuators to the exoskeleton. The study demonstrated that the device could positively transmit joint torques to the wearer without restricting mobility.

2.23 THE ASSISTON-KNEE

ASSISTON-KNEE is a self-aligning knee exoskeleton that automatically aligns the joint axes of both the exoskeleton and the knee of the wearer [38]. This reduces the set-up interval required to attach the patient to the device. A Bowden cable driven SEA actively controls the knee’s rotational degrees of freedom and a planar parallel mechanism for the translational degrees of freedom. It is light-weight and compact in design in addition to the significantly low inertia, allows for the actuator and reduction unit to be located remotely.

2.24 NEUROREX: A NEURAL ROADMAP

A brain machine interface (BMI) roadmap of translational and clinical nature was utilized by the NeuroRex, a robotic exoskeleton which was an augmented form of the Locomotor Therapy (LT) [39]. The exoskeleton model was an EEG based design with BMI capabilities. It sought to assist the mobility impaired individual to walk independently. Reports of improvement in orthostasis and vital capacity were found and the walking measures and balances of the test subjects were shown to have improved. Utilizing the study of brain activity might just be a more proper means to meet the requirement of proper motion, however the systems employed for such activities stand the question of being an economic concern for the middle-class individual.

2.25 THE STEVEN EXOSKELETON

Steven is a lightweight, assistive exoskeleton with minimal actuation and serves as a practical solution that will apply to the mobility problems in paraplegics [40]. It was developed in the Human Engineering Laboratory and was supposed to address the limitations of the antecedent models which encumbered independence and utility. STEVEN exoskeleton is depicted in figure 2.11.

The robot provided a more fluidic walking dynamics with better control of speed which added to the comfort of the pilot or the wearer. Furthermore, it was the first mobile exoskeleton that succeeded in assisting the pilot in the seated position and also introduces a new range of postures for bridging the gap between the standing and seated operations.

Figure 2.11: STEVEN

While seated, the pilot possesses postural stability and security as the device acts as the absent core muscles of the pilot. This was designed keeping the wheelchair users in mind, since the wheelchair is the cheapest, safest and most commonly used support system to provide mobility for the pelagic individuals. Tuneable hip and spine flexibility of the device helps in improving the performance and adaptability. The device and its amazing control software adaptability makes it possible to examine users of different medical conditions, ensuring variability as well.

2.26 DESIGN OF WSE

The walking supporting exoskeleton (WSE) was developed to offer support to the fundamental motions of disabled individuals who were unable to perform them partially or wholly [41].The key feature of this exoskeleton includes the adjustment of critical dimensions so as to be able to fit users of different sizes. A rigid yet mechanical structure was designed using materials of high density rate. Without the actuators the whole apparatus weighs 15kg. The term user support rate was defined and assisted in the selection of the actuators. Suitable performance tests ensured user harmony and comfort. The LiPo battery pack provided a working time of 3 hours with a single charge and that the controllers gave satisfactory joint motion control.

2.27 THE COMPACT REHAB ROBOT

CR2 or the compact rehabilitation robot was developed to train victims of stroke to achieve motion of both upper and lower limbs.[42] This novel hybrid bot performed rehabilitation training for both sets of limbs with a sitting posture integrated monitoring system. A proportional controller that has an output performance values of 0.24s and 0.19s settling time and rise time respectively was used to control the robot. It trained the individuals using an enhanced VR environment along with haptic feedback and hoped to speed up recovery of the same.

2.28 OBJECTIVES OF THE DESIGN

The objective of our project is to assist these individuals with partial paresis or partial muscular amyotrophy by designing and developing a support mechanism called the exoskeleton for them in an economical and easily accessible manner. The bi-limb exoskeleton will amplify the minimum muscular activity or any remnant of it and help in movement of the legs and feet of the individual, thereby enabling them to walk without any fear of falling without compromising in comfort or safety. It seeks to identify the various phases of movement in the human body, the load and torque values at the required points (joints) and suitably fabricate the system that is able to bear them all at a low cost since the already existing models pioneered by faculties from abroad are very costly and demand a lot of financial incentive making it quite inaccessible to the common man. It aims to identify and design the various components used in the system and analyze it so as to ensure the safety of the design.

The design is set to meet the existing limitations in the most efficient and effective of ways by contriving a low-cost model especially suitable for the typical Indian citizen. If it is developed as a product, it will be an economic alternative rehabilitation equipment as well as support system for daily purposes of every disabled individual that uses it. It can be ascertained from the results and discussions mentioned in Chapter 7, that it will be all set to meet the goal of assisting the individuals in a proper manner.

2.29 IDENTIFIED SCOPES FOR IMPROVEMENT

Most of the existing designs are costly and not affordable for a common man. Some of them cannot even be accessed unless they are members of prestigious rehabilitation centers. Hence there is a critical need for an inexpensive alternative, which should be made easily accessible as well. There is also the case of the extant designs being complex in nature. This affects the time for manufacture of the system and the scope of patients it can offer support to. Therefore, a design involving fewer complex mechanisms and inherently adaptable to any user should be contrived.

Another matter that is not discussed in many designs is the need for a suitable controller. An exoskeleton must not overpower the wearer and enforce motion against his will or manifest great alterations in the user's gait kinematics. The gait trajectory and speed should be adjusted according to match the intention of the user. By employing a proper controller with enhanced functionality, this can be achieved quite easily without the need to re-tune the controller. Such a controller, if in possession of scope for added functionality, could help in accomplishing the desired futuristic ideas presented at the end of this thesis.

Finally, the greatest limitation of it all, the incumbent desideratum of meeting the prerequisite of a being light-weight. Most of these systems are bulky and heavy which adds extra load to the user, bringing down his ability to use it continually. It is indispensable that this condition is to be met and without which the system will only retrograde its own advantages.

CHAPTER 3

DESIGN METHODOLOGY

3.1 GAIT ANALYSIS

Gait refers to the biphasic, bipedal forward propulsion of the c.g. (centre of gravity) of the body, which consists of alternated sinuous movements with the minimum expenditure of energy, of the different parts of the body. Simply put, it is the locomotion fulfilled through movement of the limbs. analysis of human body was conducted. In order to get a clear picture of this motion, various models have been studied. The concepts like hip flexion and extension, stance and swing phases, cadence, stride length and time of stride were also reviewed.

The angles of the hip and joints with positive and negative values are referred to as flexions and extensions. An individual who is standing erect would have hip and knee angles of 0 degrees, whereas one who is seated would have these values closer to 90 degrees. The gait angles are shown in figure 3.1.

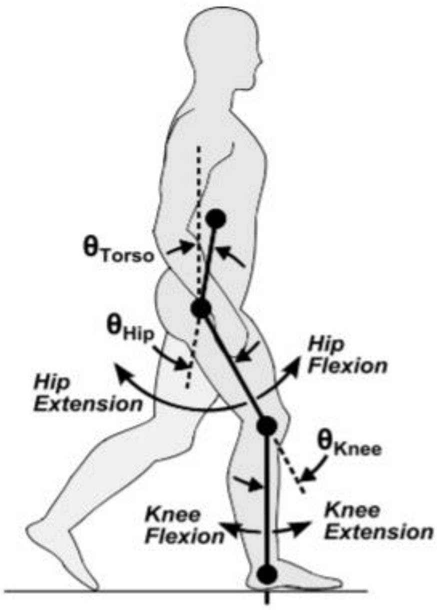

Figure 3.1: Gait angles

Human gait is a sequence of repetitive stages or phases. It is basically subdivided as stance and swing phases. This is depicted by figure 3.2 below. The stance phase is characterised by the contact of the foot with the ground, while the latter occurs when the foot is not in contact with the ground. When both are simultaneously on the ground, it is a double stance.

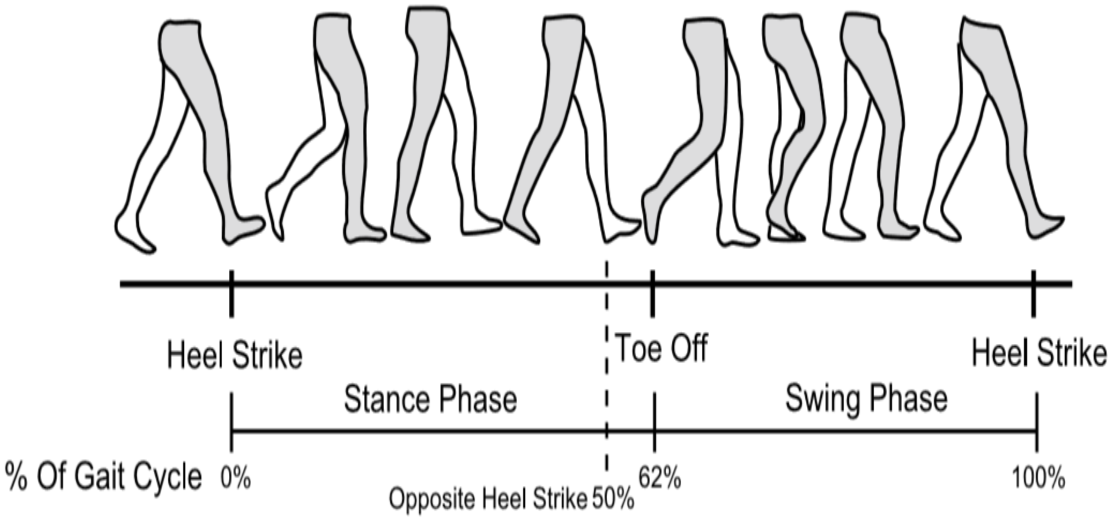

Figure 3.2: The main phases of gait

A stride is a complete cycle of one leg (e.g. heel strike to heel strike of the right leg). The stride length Ls (figure 3.3), can be defined as the distance between the two heel strikes of the same foot, and the stride time as the time it takes to complete one cycle of this process.

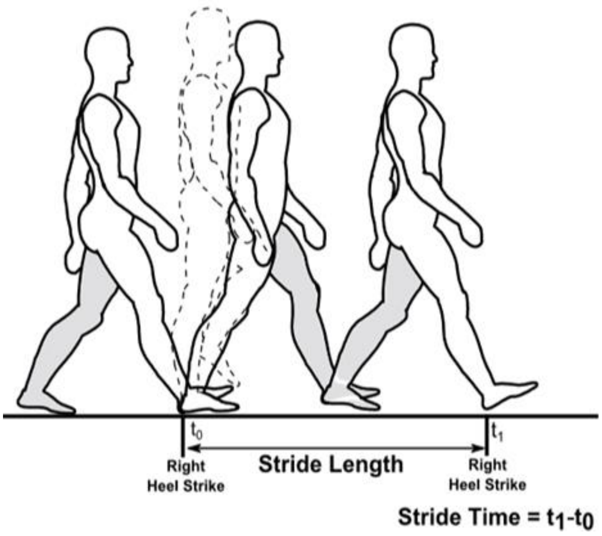

Figure 3.3: Stride length

Step length is the distance measured from one heel strike to the next of subsequent feet and is therefore half of one stride. Cadence refers to the rate of strides. Cadence can be calculated as:

Cadence=strides/minute; strides/60sec; 2*steps/60s

3.2 TORQUE CALCULATION

Exoskeleton models are generally classified as slow speed exoskeletons and high-speed exoskeletons. Our model is a slow speed exoskeleton. A theoretical dynamic analysis was conducted to determine the motor torque and the gear ratio. In the analysis, for calculating the torque needed for walking the targeted user was considered to weigh 100kg and 1.85m tall. The joint torques of the exoskeleton model was takes as T_1 for hip joint, T_2 for knee joints and T_3 for ankle joints. The forces at hip, knee and ankle joints are shown by figures 3.4, 3.5 and 3.6 respectively.

Let;

M_1= Mass of the actuator at hip joint

M_2= Mass of the thigh

M_3= Mass of the actuator at the knee joint

M_4= Mass of the shank

M_5= Mass of the actuator at the ankle joint

M_6= Mass of the foot

ML_1= Mass of the thigh link

ML_2= Mass of the shank link

ML_3= Mass of the ankle link

L_1= Length of thigh

L_2= length of shank

L_3= Length of foot

Then,

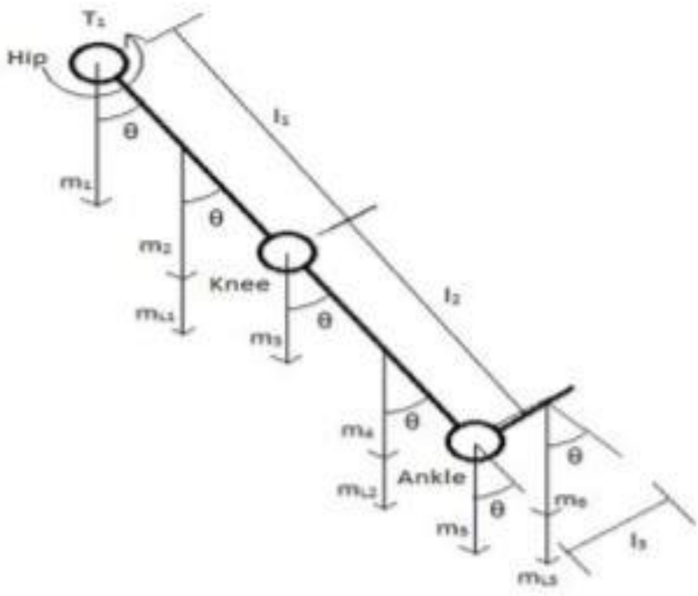

Figure 3.4 : Forces acting at hip joint [43]

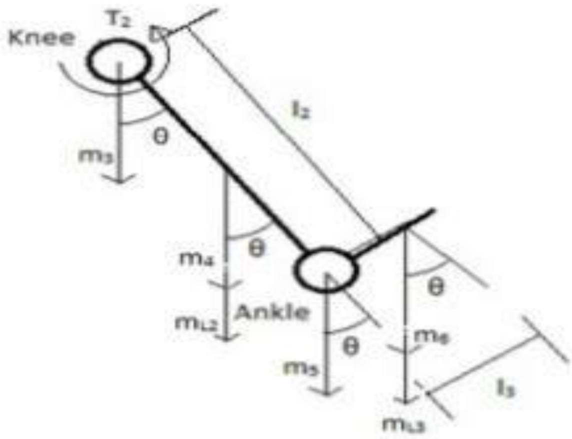

Figure 3. 5: Forces acting at knee joint [43]

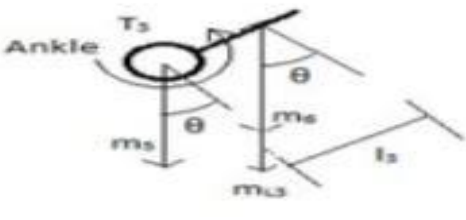

Figure 3.6 : Forces acting at the ankle joint [43]

$$T_1 = sin\theta \left[(M_2 + ML_1)g \left(\frac{L_1}{2}\right) + M_3 g(L_1) \right] + sin\theta \left[(M_4 + ML_2)g \left(\frac{L_2}{2} + L_1\right) \right]$$
$$+ sin\theta [M_5 g(L_2 + L_1)] + sin\theta [(M_6 + ML_3)g(L_2 + L_1)]$$
$$+ \cos\theta \left[(M_6 + ML_3)g \left(\frac{L_3}{2}\right) \right] ,$$

$$T_2 = sin\theta \left[(M_4 + ML_2)g \left(\frac{L_2}{2}\right) \right] + sin\theta [M_5 g(L_2)] + sin\theta [M_6 g(L_2)]$$
$$+ \cos\theta \left[(M_6 + ML_3)g \left(\frac{L_3}{2}\right) \right] ,$$

$$T_3 = \cos\theta \left[(M_6 + ML_3)g \left(\frac{L_3}{2}\right) \right]$$

T_1, T_2, and T_3 obtained were 47.56 Nm, 21.68 Nm and 2.10Nm respectively. Therefore, more torque should be produced by the motor and drive system, than the values calculated to lift both the exoskeleton and the user's limb. As we are focused on providing the motor on the hip, this gives a result for the torque that is needed by the motor on the hip of the exoskeleton.

3.3 RELEVANT SELECTIONS

The team studied the designs of various models that were designed earlier. At first the ostrich model, which was more concerned with supporting more weight and offered flexibility in design was considered.

3.3.1 FINALISING THE MATERIAL

Since steel proved to be very heavy inspite of being strong and rigid, and carbon fibre was too costly to consider as it would become a burden on the net expense as a whole, aluminum alloy was finalised to be chosen as the material. It was light-weight, and strong unlike steel and was not as costly as carbon fibers as well. After comparing the values of corrosion resistance, weldability, machinability, formability, strength and workability of the different alternatives, a conclusion was made , which was that the most efficient aluminium alloy for building the design would be T6061. It is a precipitation-hardened aluminum alloy, containing magnesium and silicon as its major alloying elements. It has a Young's modulus of 68.9 GPa and tensile strength up to 290MPa. It has good mechanical properties, exhibits good weldability, and is very commonly extruded.

3.3.2 THE TYPE OF SENSOR

The next task was to choose the appropriate sensing mechanism to comprehend the intention of motion of the paraplegic person. A detailed study about various pressure sensors, piezoelectric sensors, force sensors were conducted. The pros and cons of a force sensitive resistor was analyzed and was chosen due to various advantages like size, low cost and ability to withstand higher shocks. Piezoelectric sensors are difficult to calibrate. Even minute forces can be calculated using FSR (high sensitivity).

3.3.3 SELECTION OF ACTUATOR

Upon properly reviewing various previous designs and their actuator systems, it was concluded that the use of electric actuator system owing to its simplicity, availability, economy and ease of operation. Motors offering varied amounts of peak torques are available and they could be chosen according to the required torque and shaft diameter. Moreover, the other systems were bulky, heavy and required much space. They also possessed lower power to weight ratios compared to electric drives.

3.4 PHYSIOTHERAPIC ATTRIBUTES

Since the design that was being developed was for the use of common man, it was very import to understand the difficulties that were existing with the devices that were commonly utilised by the general public. A physiotherapist daily intervenes and assists in the rehabilitation of individuals who are suffering from paralysis. Therefore, an appointment was made with a known physiotherapist in the neighbourhood and the various concerns were discussed.

During the session with physiotherapist, the hinge angle limits of the ankle joint, were found to be between 0-8°. The angle between the downward pointing direction to horizontal resting position lies in midst of 0-5 degrees and 5-8 degrees from horizontal position to upward position. The essentiality of having a perfect knee locking mechanism was discussed. It was found that:

- It was advisable to use crutches with an exoskeleton to offer a potentially balanced state and to improve the feeling of safety among the individual.
- The sensor that creates the movement of the exoskeleton limb is only supposed to move when one leg is strictly in contact with the floor. Else the subject will fall forwards.
- Excessive weight of the exoskeleton will be hard for the subject to carry around and hence the efficiency of the exoskeleton drops by a great amount.
- Heavy rods that have high strength and rigidity comes with heavy complications.

An average Indian weigh around 75kgs.Human body weight is supported and lifted by thigh muscles. While climbing upstairs, legs are placed first then the crutches are followed. While descending downstairs, the crutches are placed in the bottom stair first followed by legs. An average person weigh about 75kg as discussed before. Total leg weight accounts for 16.76% of total weight which is 12.53 kg.

The thigh is 10.52%=7.875kg

Leg + foot=6.18%=4.635kg

Hence total leg weight can be rounded off to 18.49%=13.8kg.

Net weight of both limbs= 27.6kg.

3.5 BASIC WORKING OF THE DESIGN

Based on all the data collected, a model was set to be made. The basic idea of the working of the system was proposed. The intent for motion from the legs will be detected by the sensors which will communicate it to the controller.

The controller (NI myRIO) will receive these signals, identify them and provide the necessary input to make the motors work. The motors are connected to the skeletal design and will actuate the motion. The skeleton is attached to the body and thus will help the person move. Figure 3.7 below shows the flow of control of the system. It illustrates the manner in which the motion shall occour..

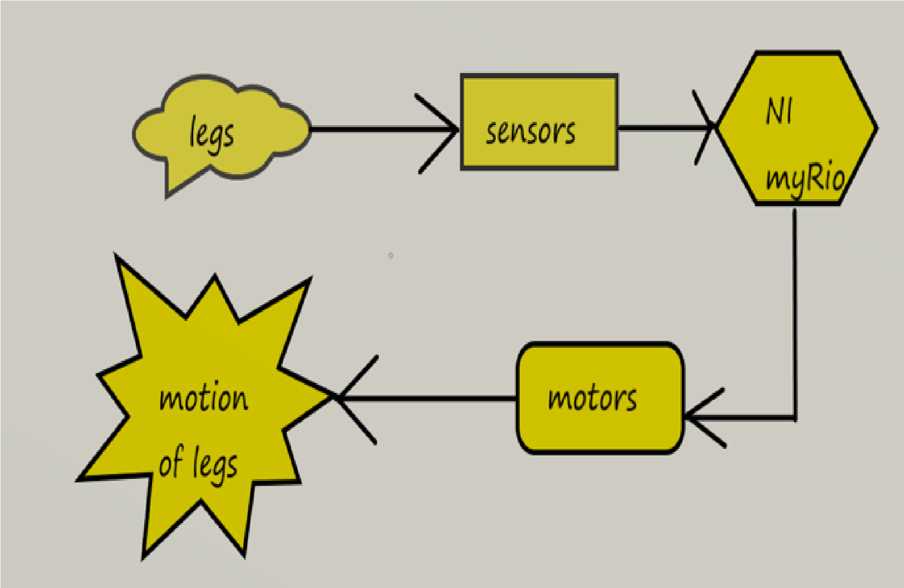

Figure 3.7: Control flow diagram

CHAPTER 4

MODELLING OF THE SKELETON

4.1 THE INITIAL MODEL

The basic model as in figure 4.1, contained a thigh link and a shank link for each exoskeleton limbs and a common hip supporting structure. It was designed with arbitrarily chosen values of torque and dimensions and was 3D-printed. Hinge joints were attached to either leg and connected it to the hip supporting structure. Random motors of 12V rated voltage and 60 rpm, offering the minimal torque requirement was also selected. This was done to check the motion in each limb.

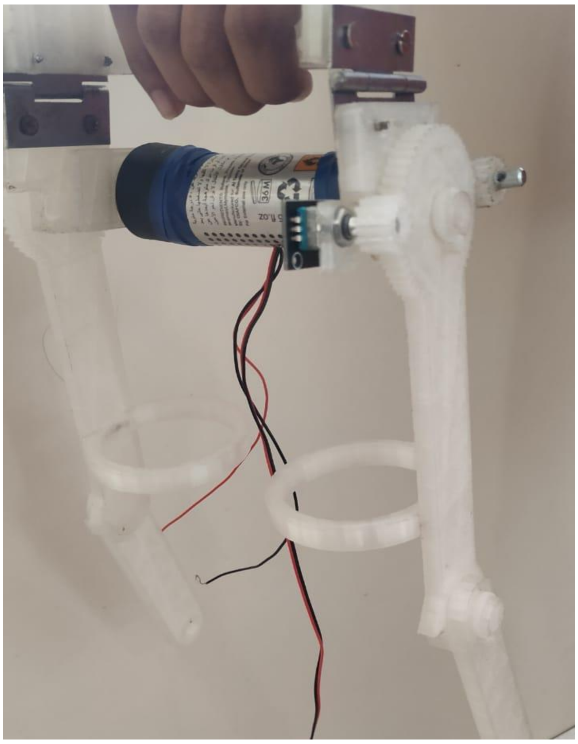

Figure 4.1: The Initial Base Model

4.2 THE SECOND MODEL

The second model was designed in CATIA V5. The motor that was selected for this model was PN01007. The CAD model of PN01007 is shown in figure 4.2. The specifications of this motor were:

Rated Voltage: 13.5V, D.C.

Rated Current: 6 A

Rated RPM: 50 RPM

Rated Torque: 6 N-m

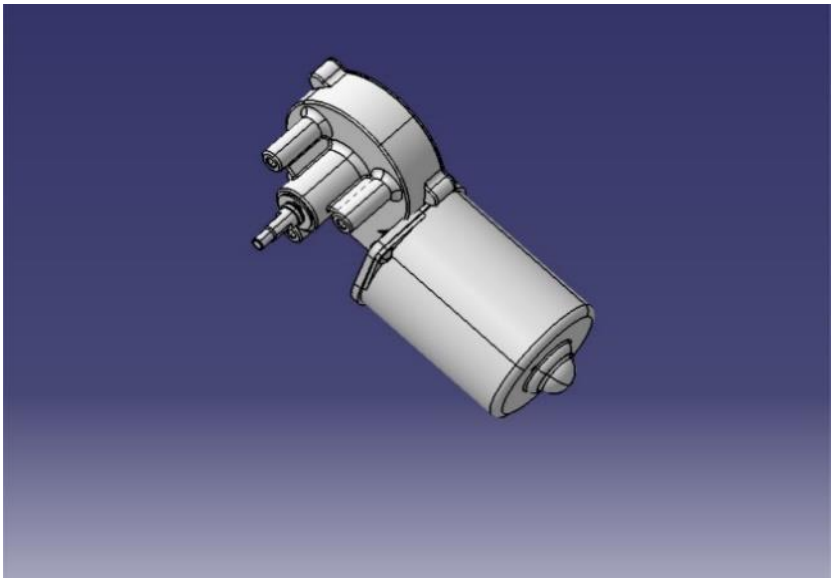

Figure 4.2: CAD Model of PN01007

The motor already contained a beveled gear assembly so that the power can be transmitted through perpendicular directions. The thigh link and the motor assembly were pivoted at the joint where it meets the hip (figure 4.3). The shank link and hip link joint is constricted in design. This was done in order to restrict unwanted degrees of freedom. The thigh link was designed in such a manner that it contained gear teeth at one end in order to transfer power from the motor to the thigh link. The gear was designed in such a way that the gear ratio was maintained at 5. The closer look at geared section is shown in figure 4.4.

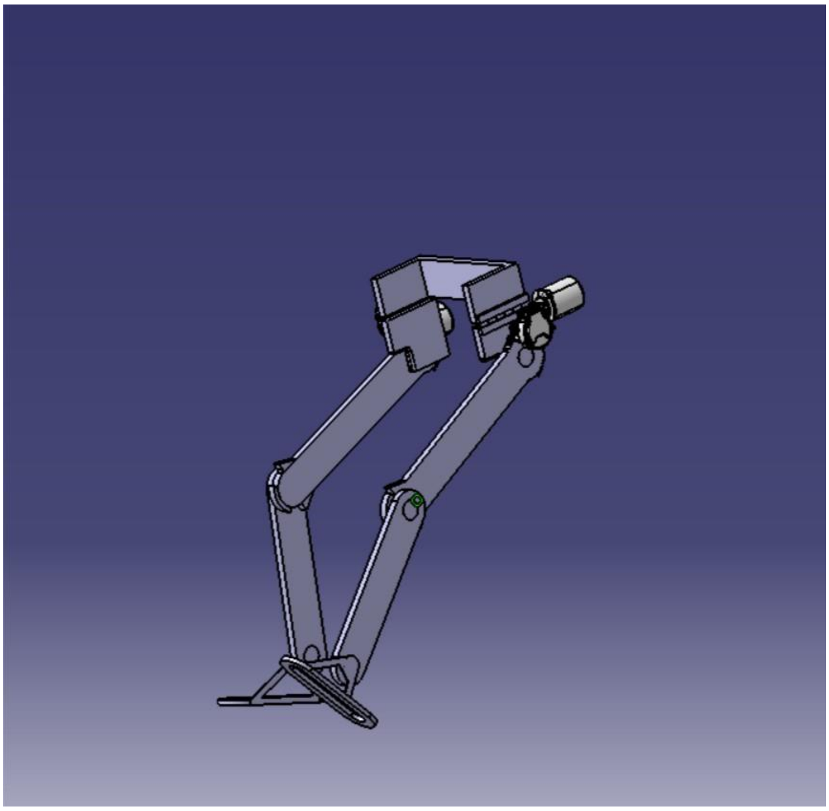

Figure 4.3: The assembled model

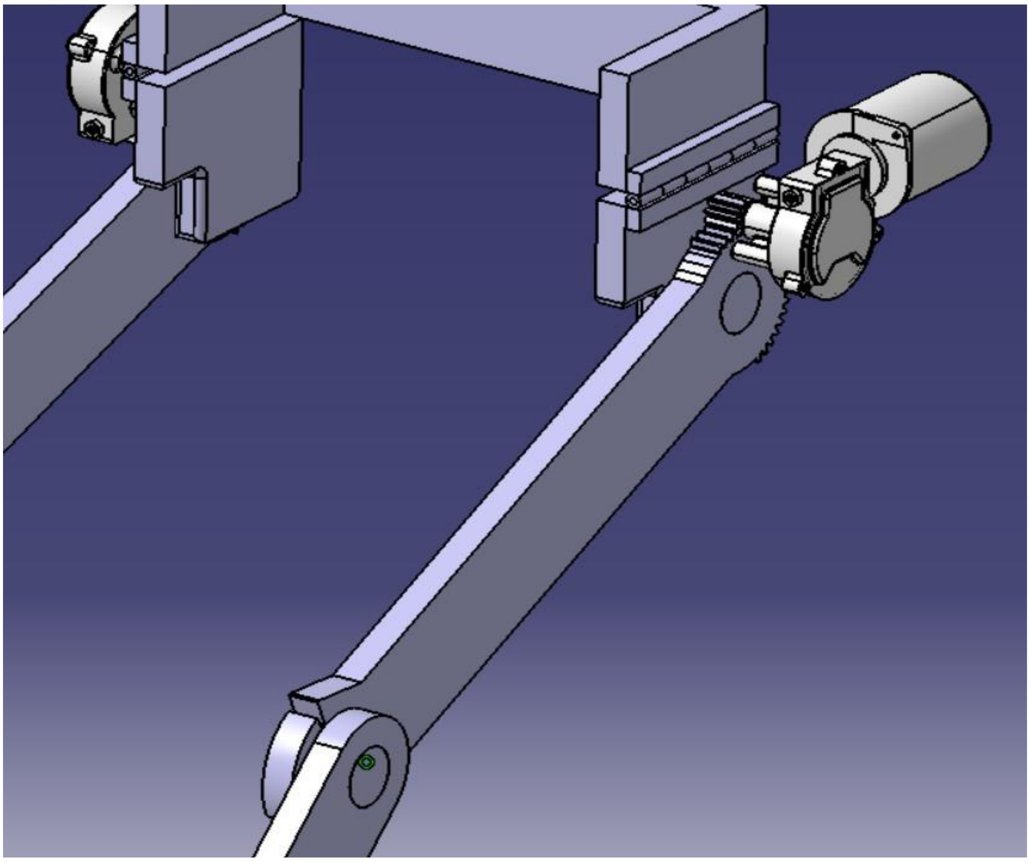

Figure 4.4: A closer look at the geared sections

4.3 THE FINAL DESIGN

The next advancement in our design was made by fixing the gear on the projection, provided along with the hip supporter. This gear assembly is of straight bevel gear type. The thigh link was produced with a hole in the top most portion in order to incorporate the gear from the hip supporter. The motor with the pinion was fixed onto the things link. In this particular model, as the motor rotates the pinion, it moves along the stationary gear in such a way that this action prompts the motor attached to the thigh link to rotate in both clockwise and anticlockwise direction. This model comes with a unidirectional locking mechanism. The motor that was finally chosen already comes with a potentiometer. The hip design also consists of a small projection to restrain the lateral movement of the thigh link beyond a limit. There is a design change in shank link to support this mechanism. The assembly of final model is depicted in figure 4.5. The shank link contains many teeth cuts in such a way that it restricts the motion to a single direction. The following are the details of the gear system used: Module: 2, No: of Teeth of Gear: 25, No: of teeth of Pinion:12, Pressure Angle:20, Face Width: 10mm, Hub Diameter: 50mm, Nominal Shaft Diameter: 22. Side view of geared end is shown in figure 4.6.

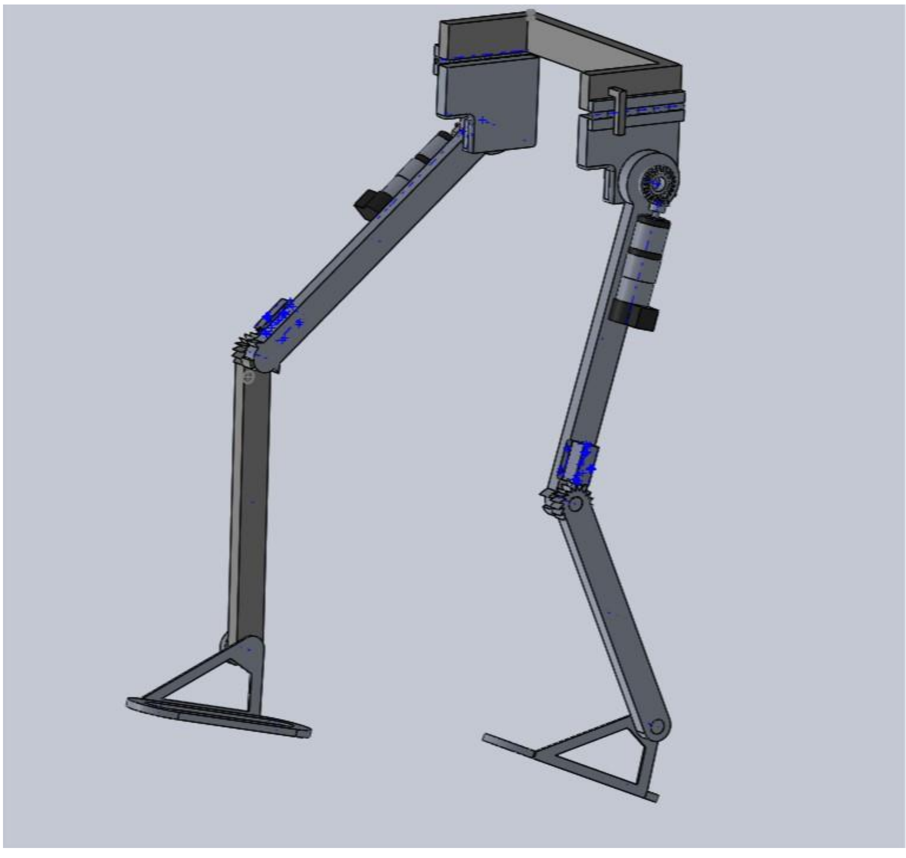

Figure 4.5: The assembly of the final model

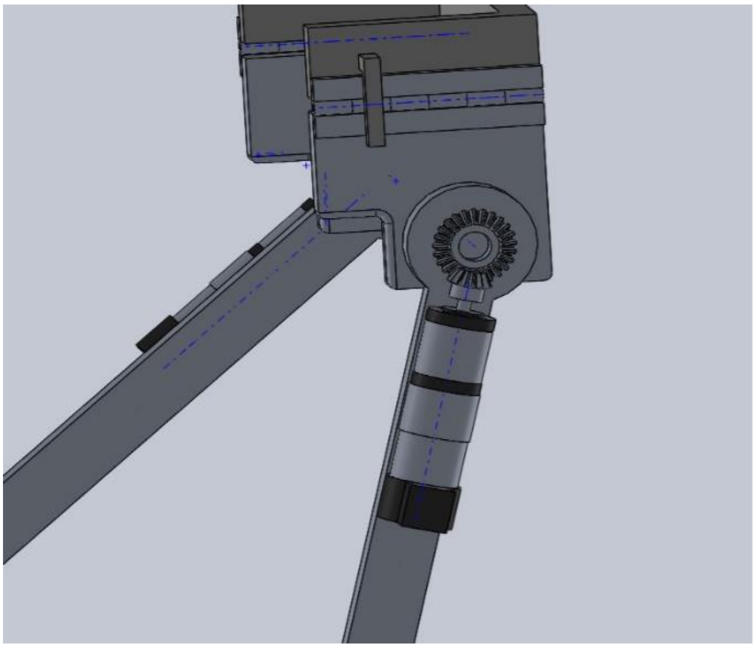

Figure 4.6: Side view of the geared ends

In order for proper functioning of the exoskeleton, when a foot is contact with the ground further motion of its knee shouldn't be possible. In order to ensure that when a foot touches the ground, a sensor should be triggered to send the corresponding signal to activate the knee locking mechanism. This is due to the reason that in its absence the subject has the risk of falling down. When the foot is no longer in contact with floor, the knee locking mechanism must deactivate for the free movement. This locking mechanism is accomplished by using a solenoid system. A closer look at the knee joint is given in figure 4.7 below. A force sensor is attached to the foot of the exoskeleton. While programming, a threshold force corresponding to the force experienced by the leg when it is placed on the ground is recorded and fed to the controller. When the foot is on the ground, the knee locking mechanism is in active stage as there is a rod projecting out of the solenoid with it's end attached to a piece shaped like a right angled triangle. This will stay in contact with the gear tooth shaped projections on the shank link and restricts its motion. During this stage the shank link can only rotate in one direction which is upward direction. When the foot is lifted from the ground and is in the air, the sensor stops experiencing the force of the threshold magnitude. This triggers the control to send an output signal that activates the solenoid and this action leads to the withdrawal of the rod from the shank link teeth. This removes the restriction of the shank link to rotate backwards and hence at this stage the shank link can move both upwards and downward directions.

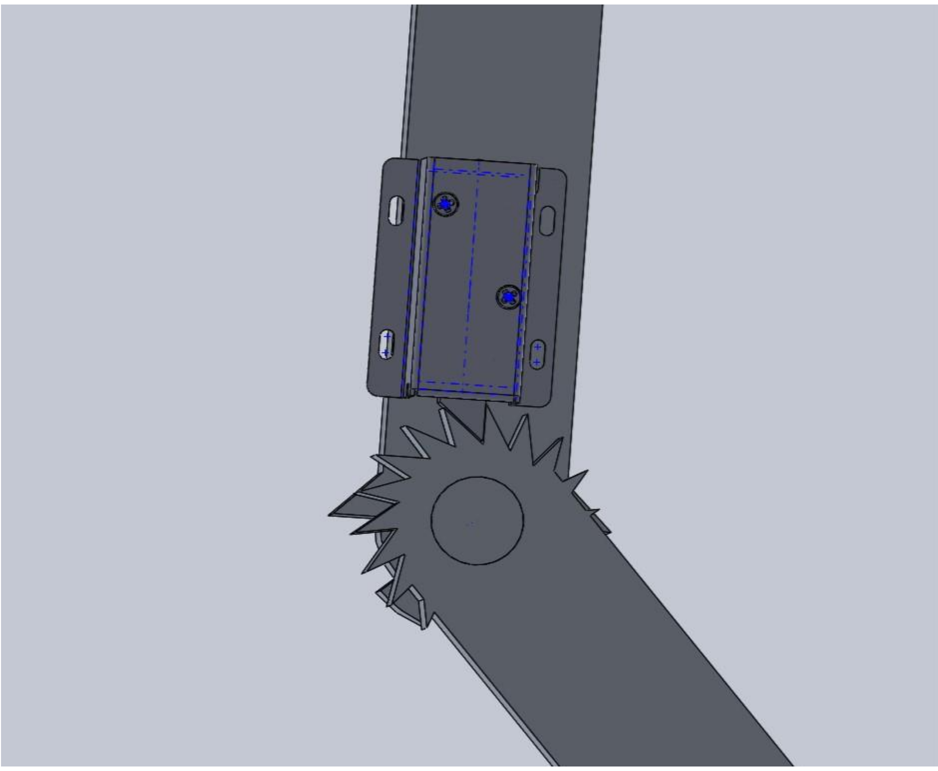

Figure 4.7: A closer look at the knee joint

When the subject shows the intention of motion, the sensors in the frontal part of legs to the side of hips detects it. For the sensor to identify this, the user must be able to exhibit a fixed scale of motion of his legs. This is due to the fact that for the sensors to activate, a fixed threshold magnitude of force should be applied in these sensors. The threshold magnitude is very small in the case of a force sensor and it is highly sensitive. This eventually leads to the transference of a signal to the motor and the motor imparts the sufficient torque for this motion. Similarly, there are sensors behind both the thighs to detect the motion of leg backwards and provide the links with a motor rotation in the opposite direction.

This model of our project therefore, contains a hip support, things link, shank link and foot link. All the links are connected together by pivot joint rather than using the actuator units as joints. This design will help avoiding direct load application on motors which will damage the actuator unit as there is limitation for its overhung load. There is usage of hinges in the exoskeleton model in order to enable lateral movements were considered. The hinges are placed on the joint where hip and thigh comes in connection. The position of hinges also promotes a future scope of motorizing the model. A restriction was given to hinges in order to stop full-fledged lateral movements. This was done by providing a projection just above this joint to control the motion of the hinges. The braces off the exoskeleton model is designed to be covered using Velcro for easy and fastening action. It is advantageous to minimize the size of support pads in order to reduce overall mass and insulating properties. Moreover, by increasing contact area, it is possible to reduce tissue pressure and thereby reduce the odds of pressure sores. However, users experience heat as a result of covering large regions of the body with foam.

4.4 PARTS OF THE MODEL

4.4.1 BEVEL GEAR

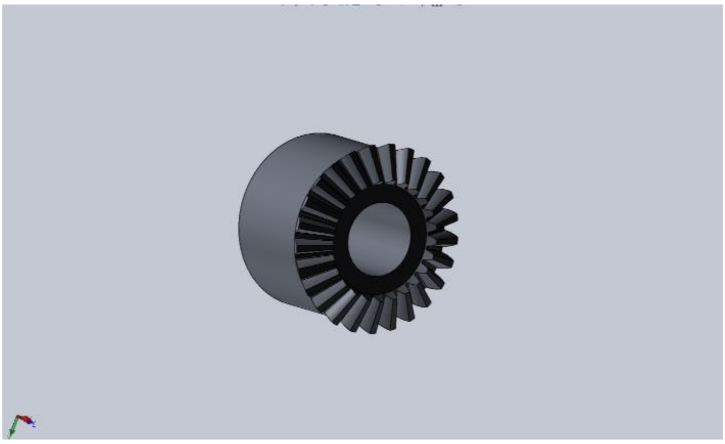

Figure 4.8: CAD Model of Bevel Gear

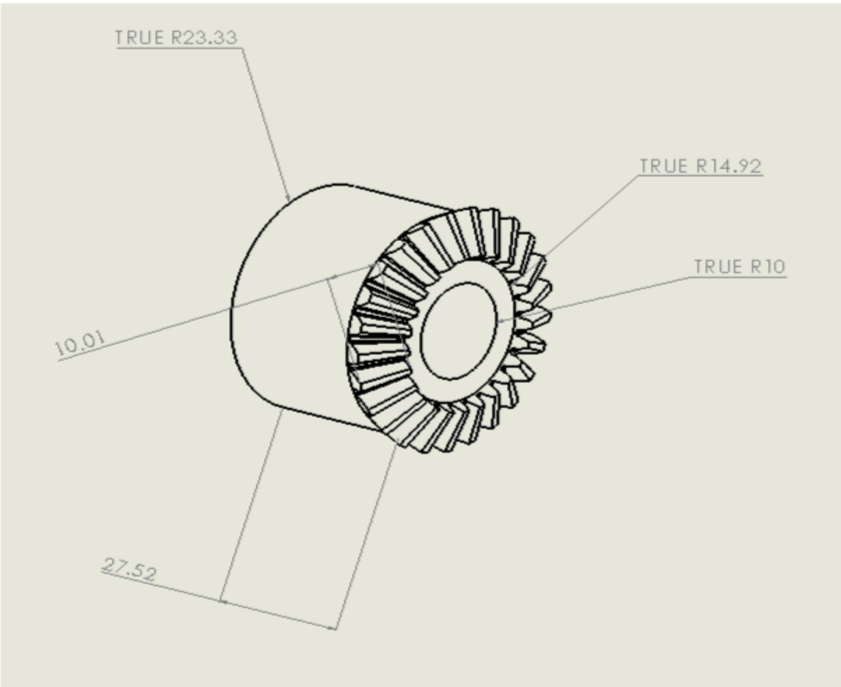

Figure 4.9: Dimensions of the Bevel Gear

4.4.2 BEVEL PINION

Figure 4.10: CAD Model of Bevel Pinion

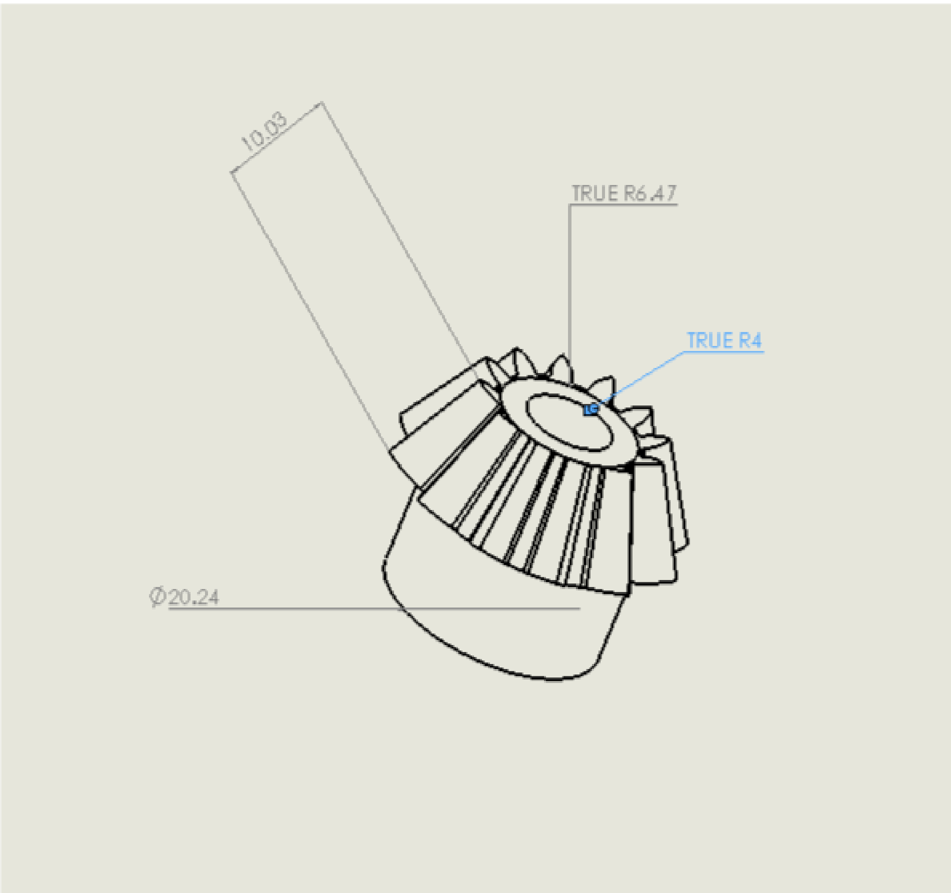

Figure 4.11: Dimensions of the Bevel Pinion

4.4.3 HINGE ASSEMBLY

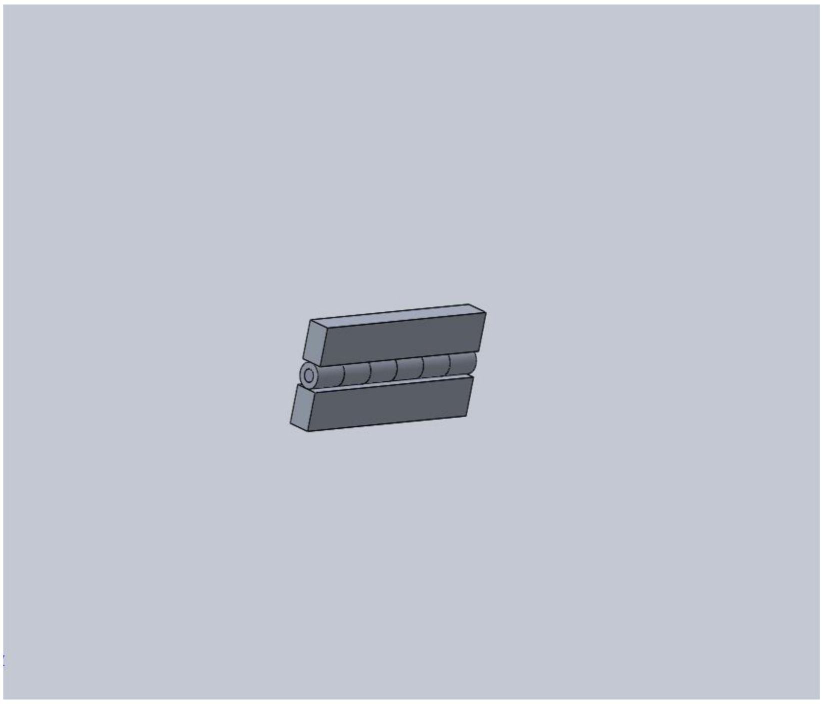

Figure 4.12: CAD Model of Hinge Assembly

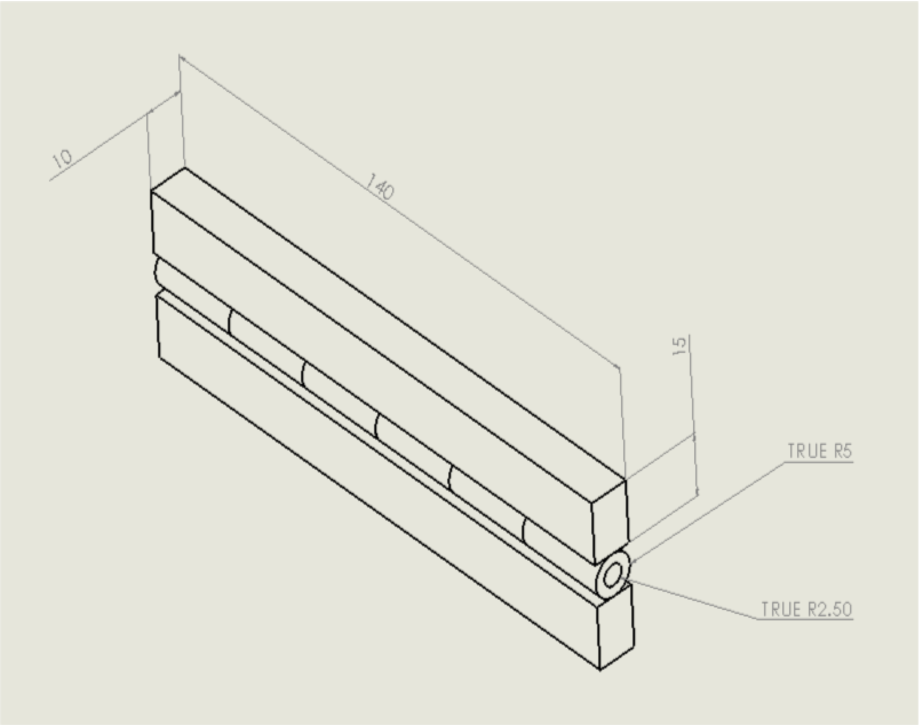

Figure 4.13: Dimensions of the Hinge Assembly

4.4.4 HINGE ROD

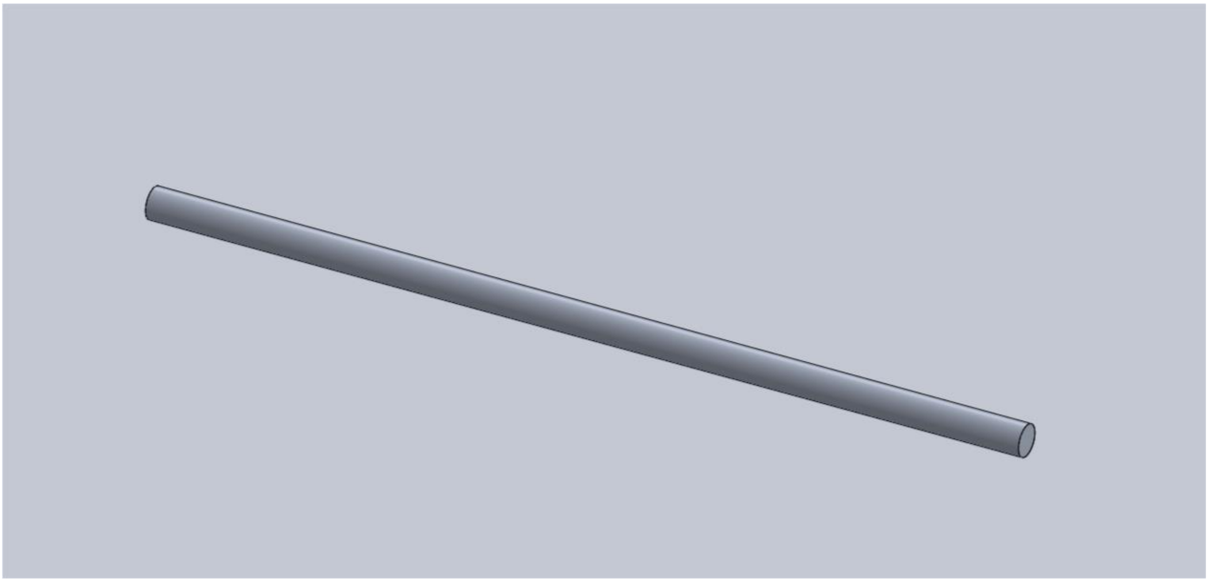

Figure 4.14: CAD Model of Hinge Rod

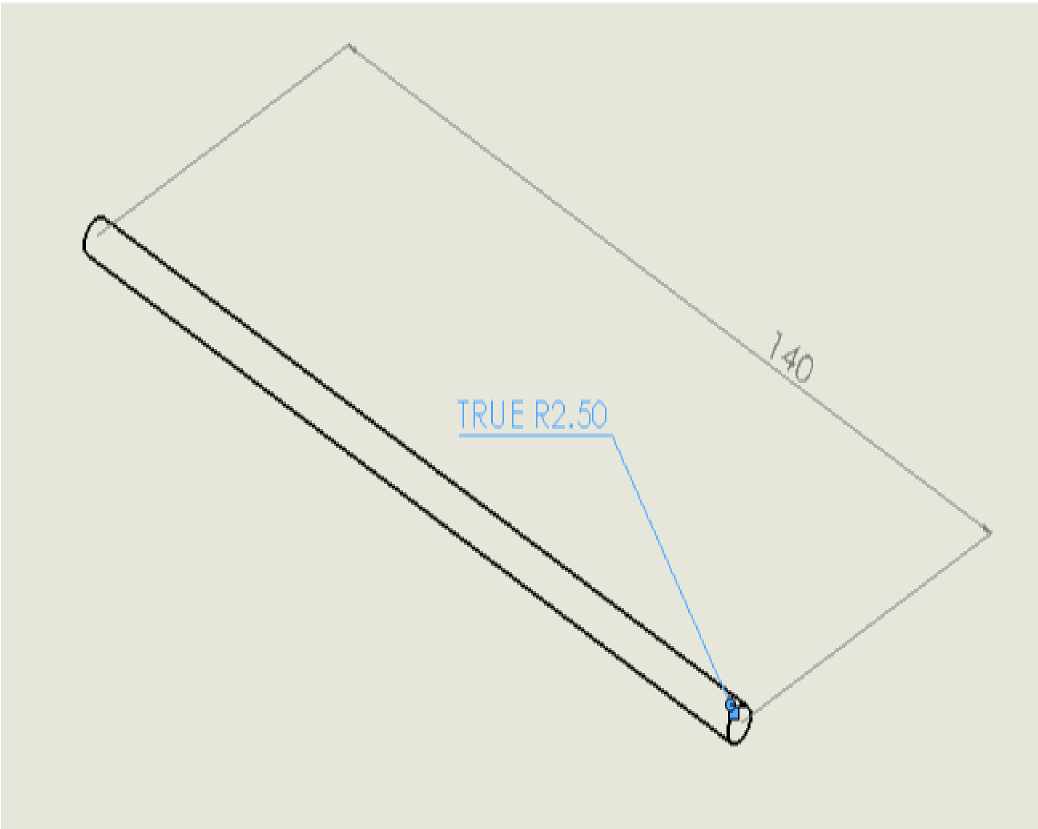

Figure 4.15: Dimensions of the Hinge Rod

4.4.5 HIP LINK

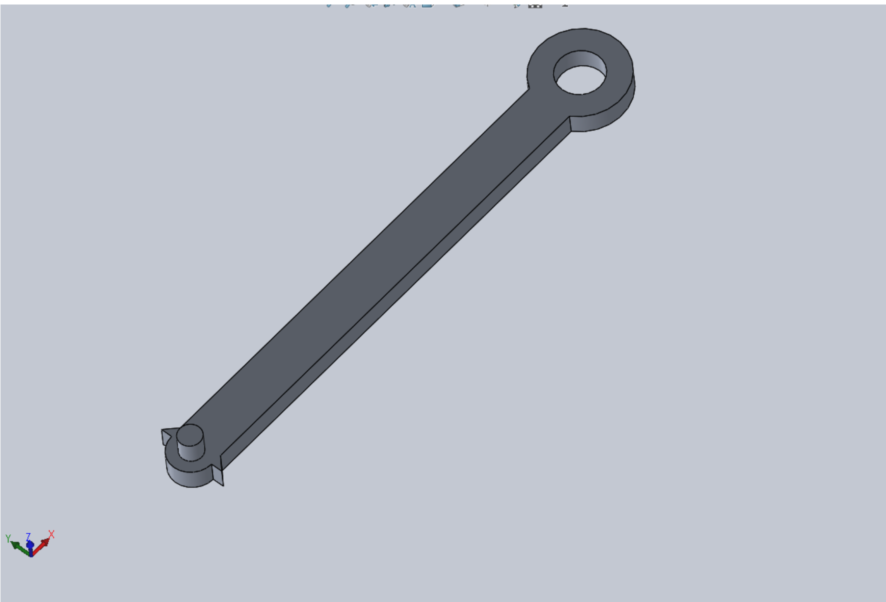

Figure 4.16: CAD Model of Hip Link

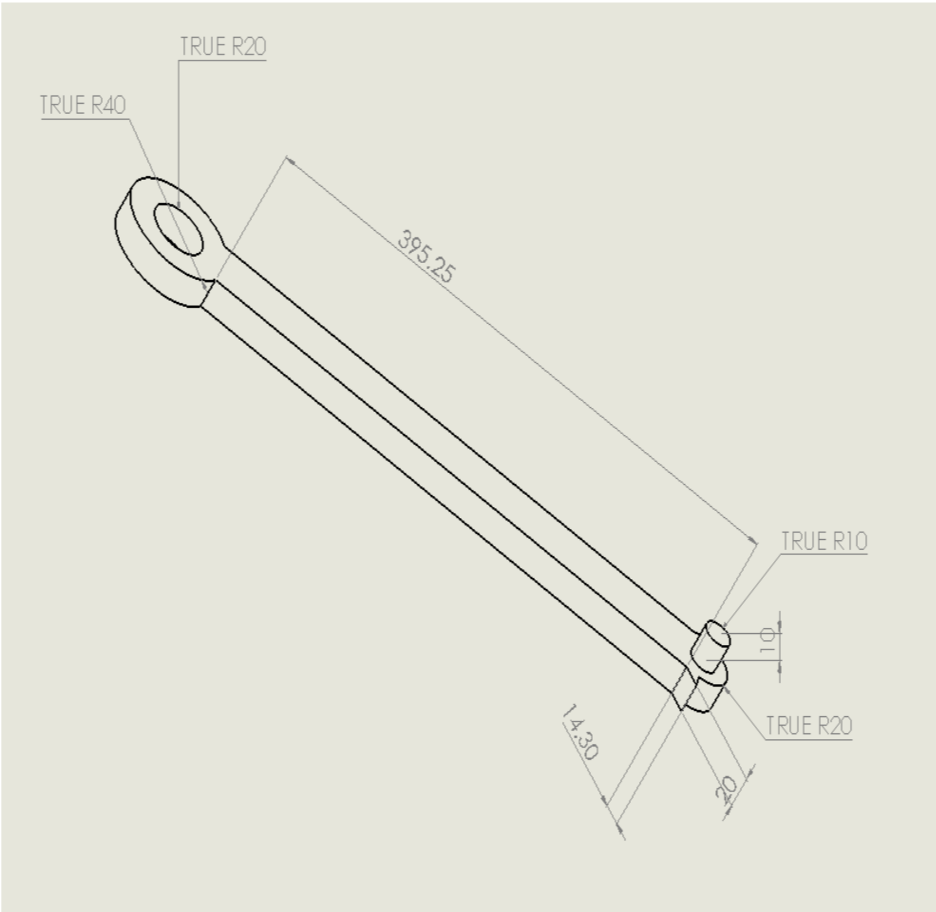

Figure 4.17: Dimensions of the hip link

4.4.6 HIP SUPPORT SIDES

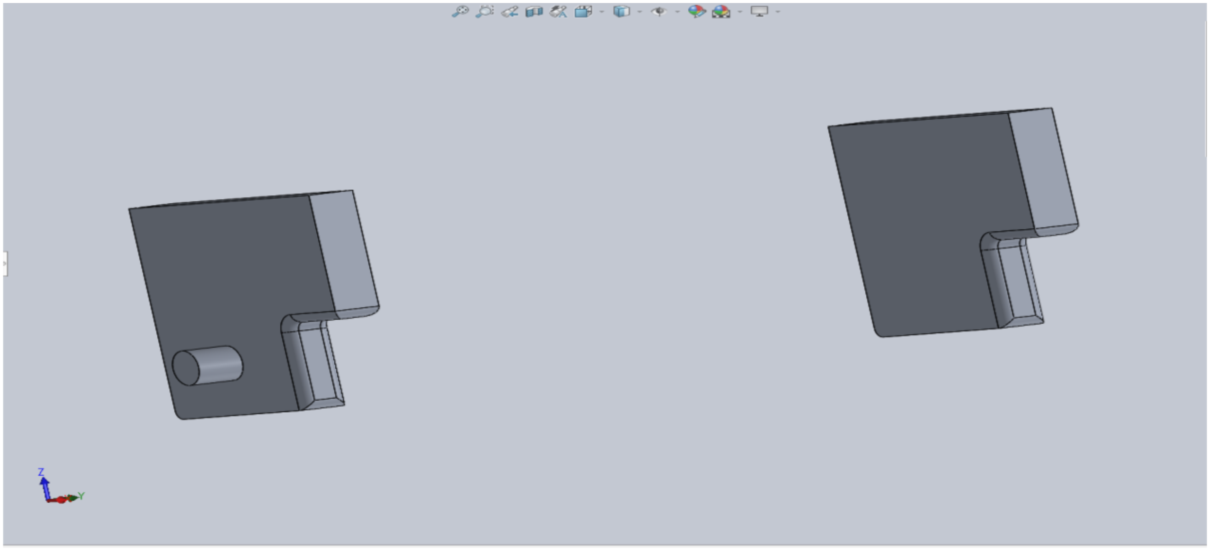

Figure 4.18: CAD Model of either lower supports of hip

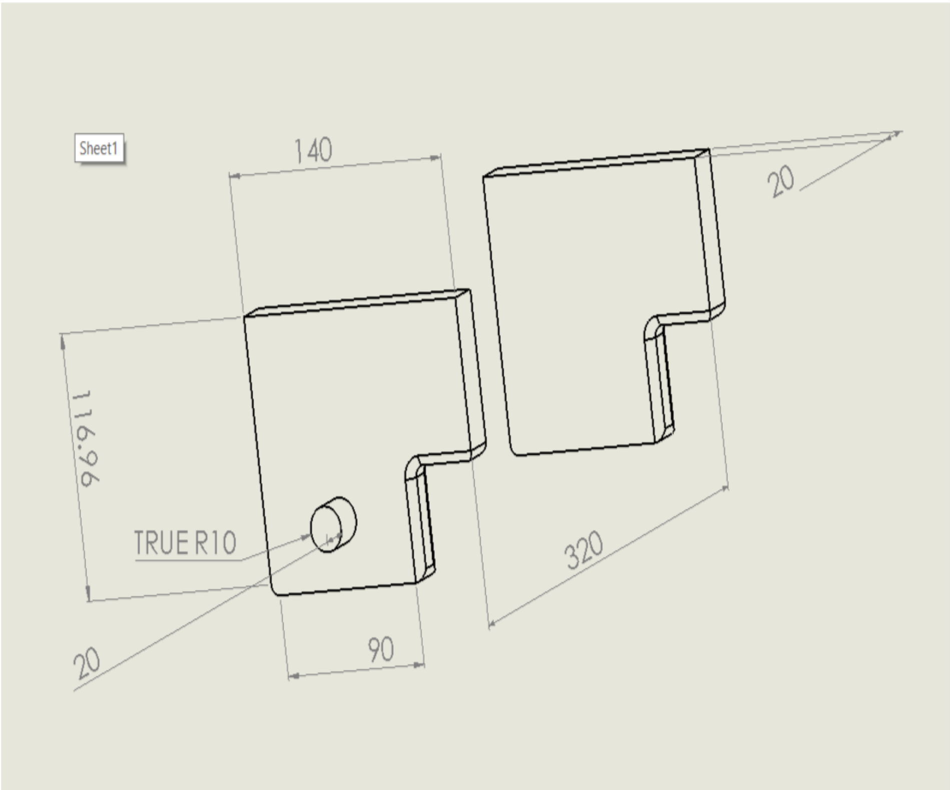

Figure 4.19: Dimensions of the lower supports of the hip

4.4.7 HIP SUPPORT UPPER PART

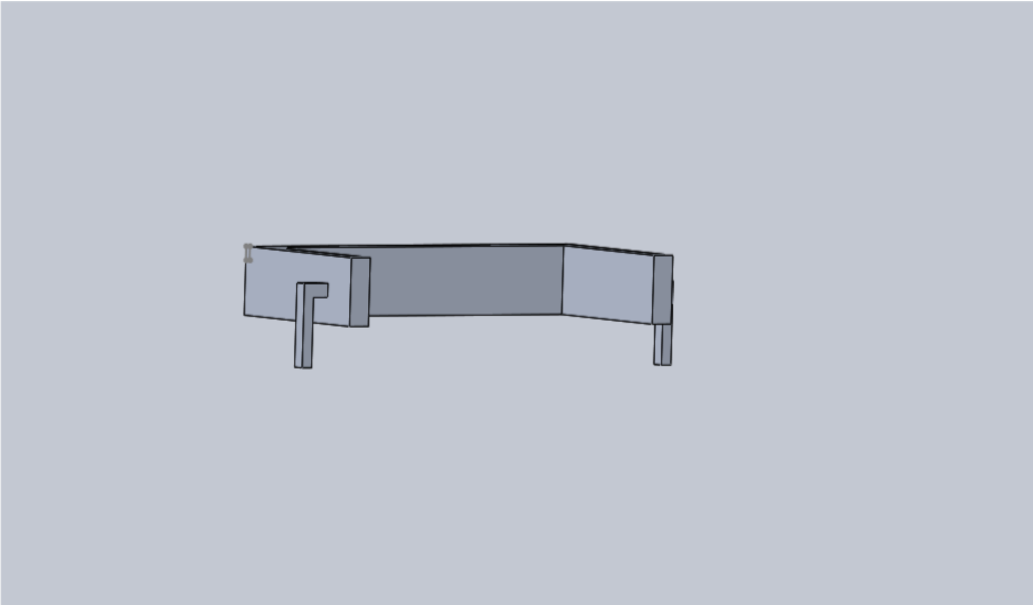

Figure 4.20: CAD Model of upper part of hip support

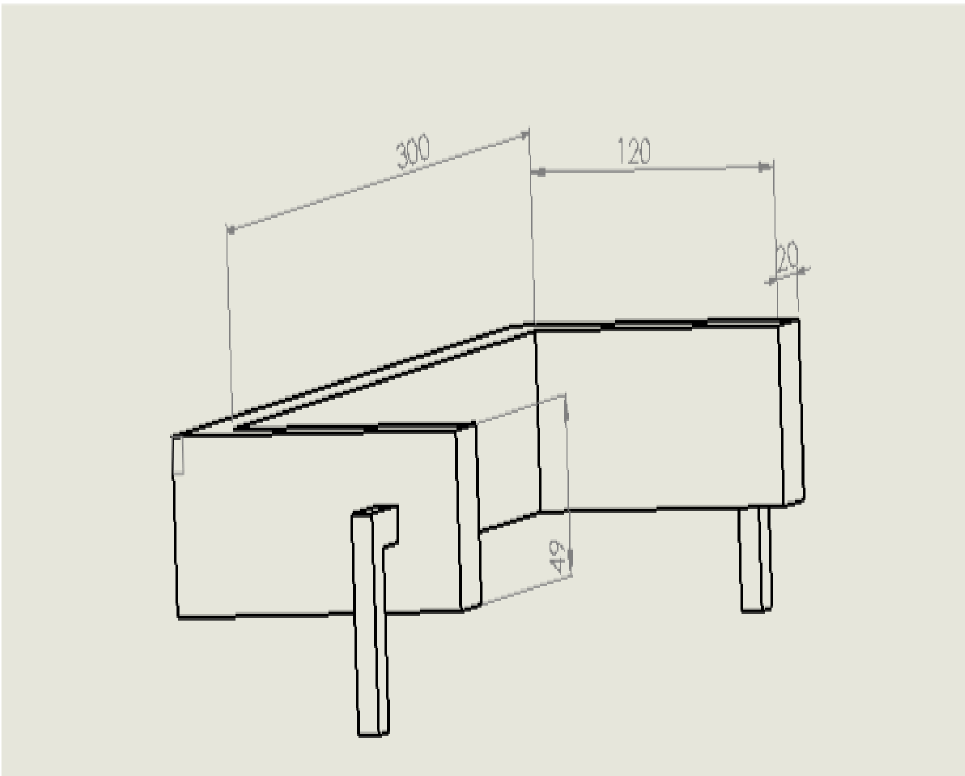

Figure 4.21: Dimensions of the upper part of the hip support

4.4.8 KNEE LINK

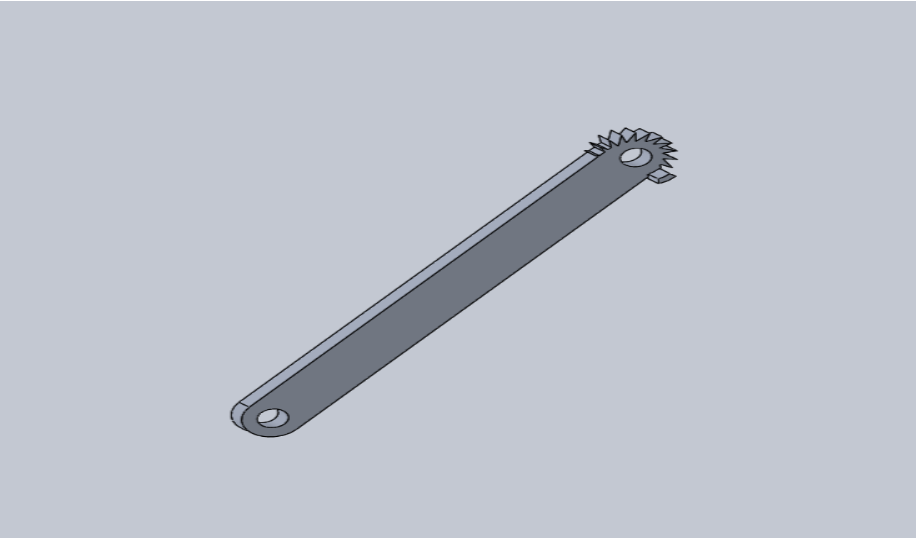

Figure 4.22: CAD Model of Knee link

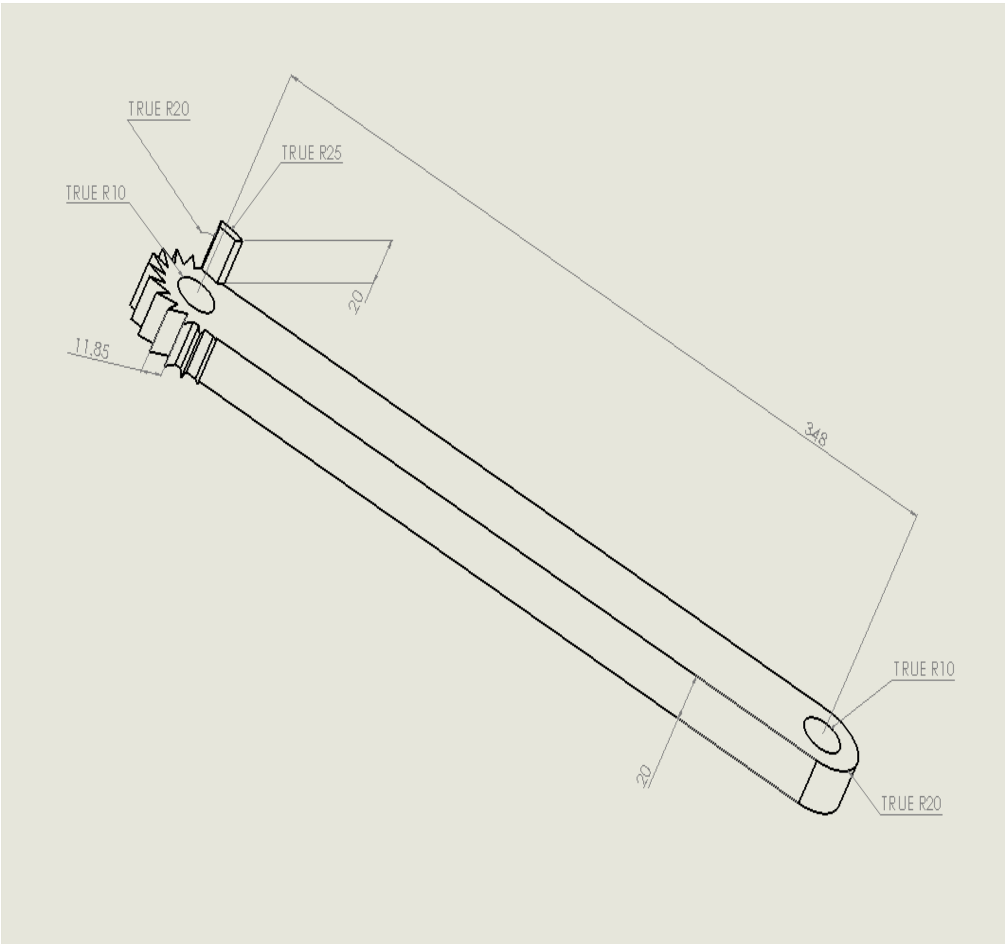

Figure 4.23: Dimensions of the Knee link

4.4.9 KNEE-LOCKING MECHANISM

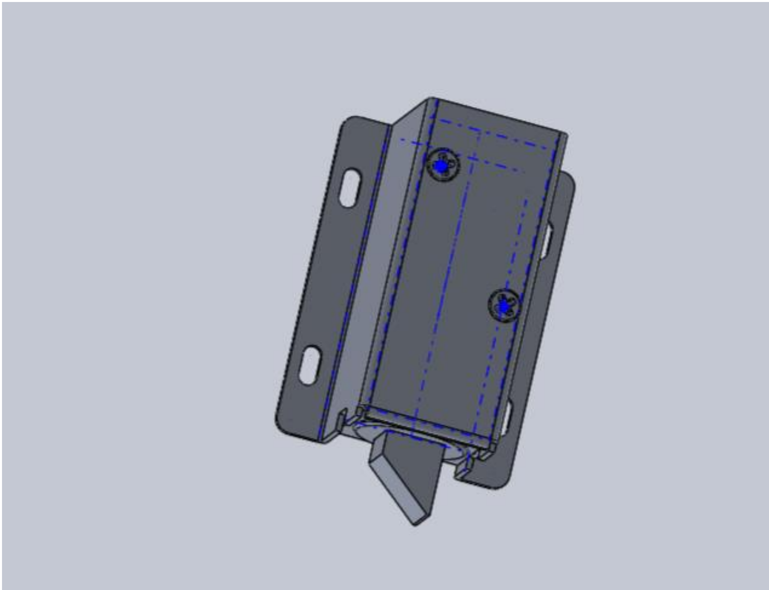

Figure 4.24: CAD Model of Knee-locking Mechanism

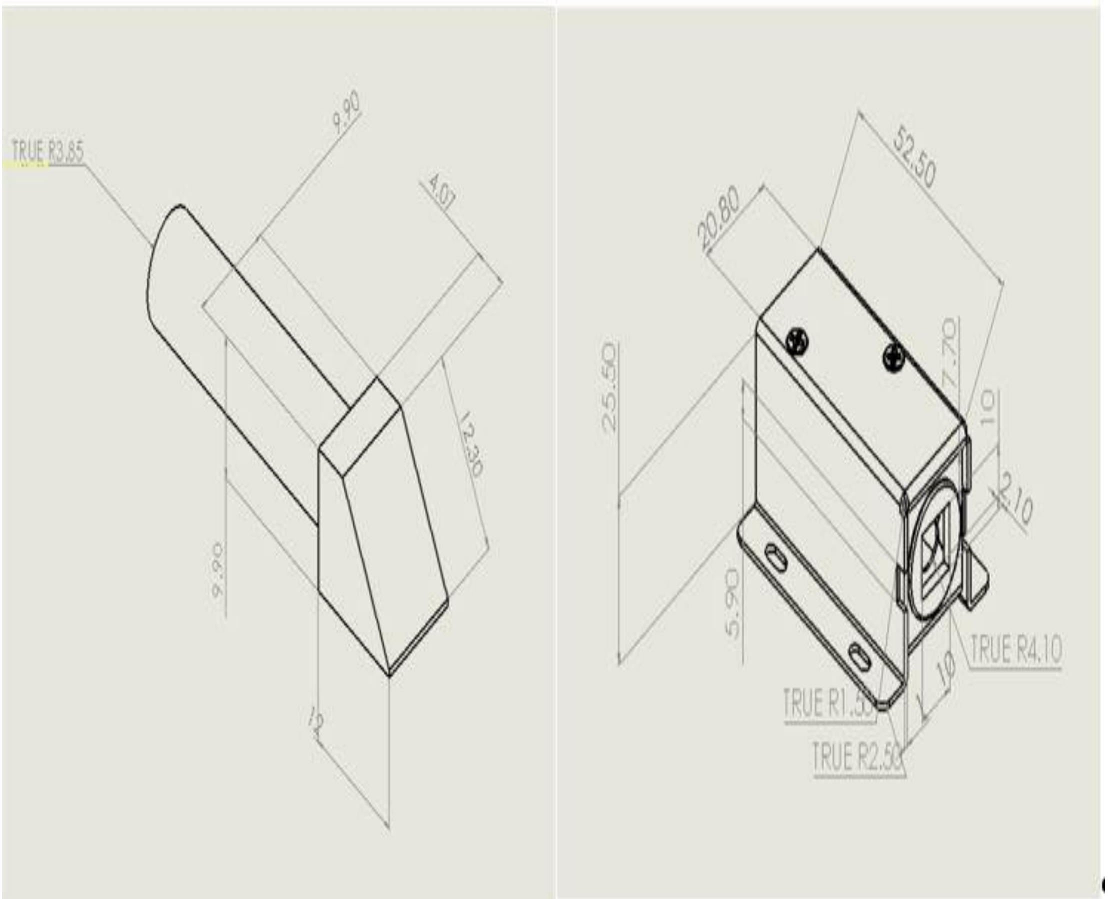

Figure 4.25: Dimensions of the parts of the Knee-Locking Mechanism

4.4.10 MOTOR

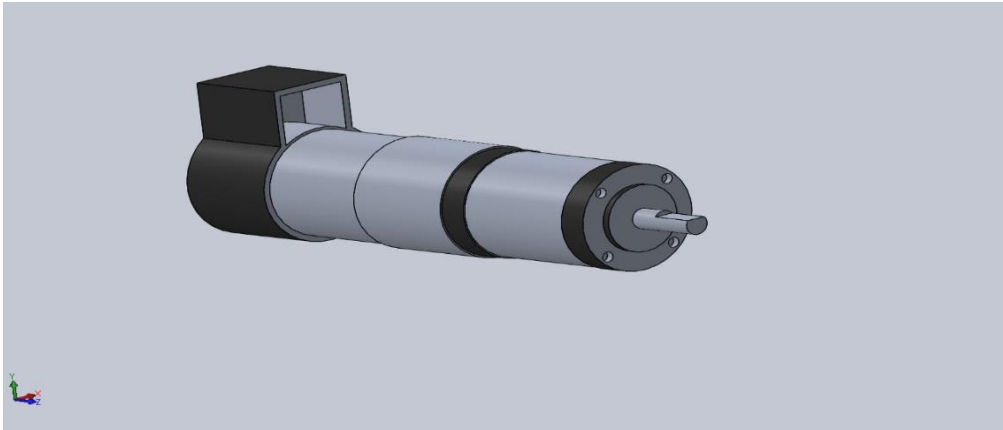

Figure 4.26: CAD Model of motor used

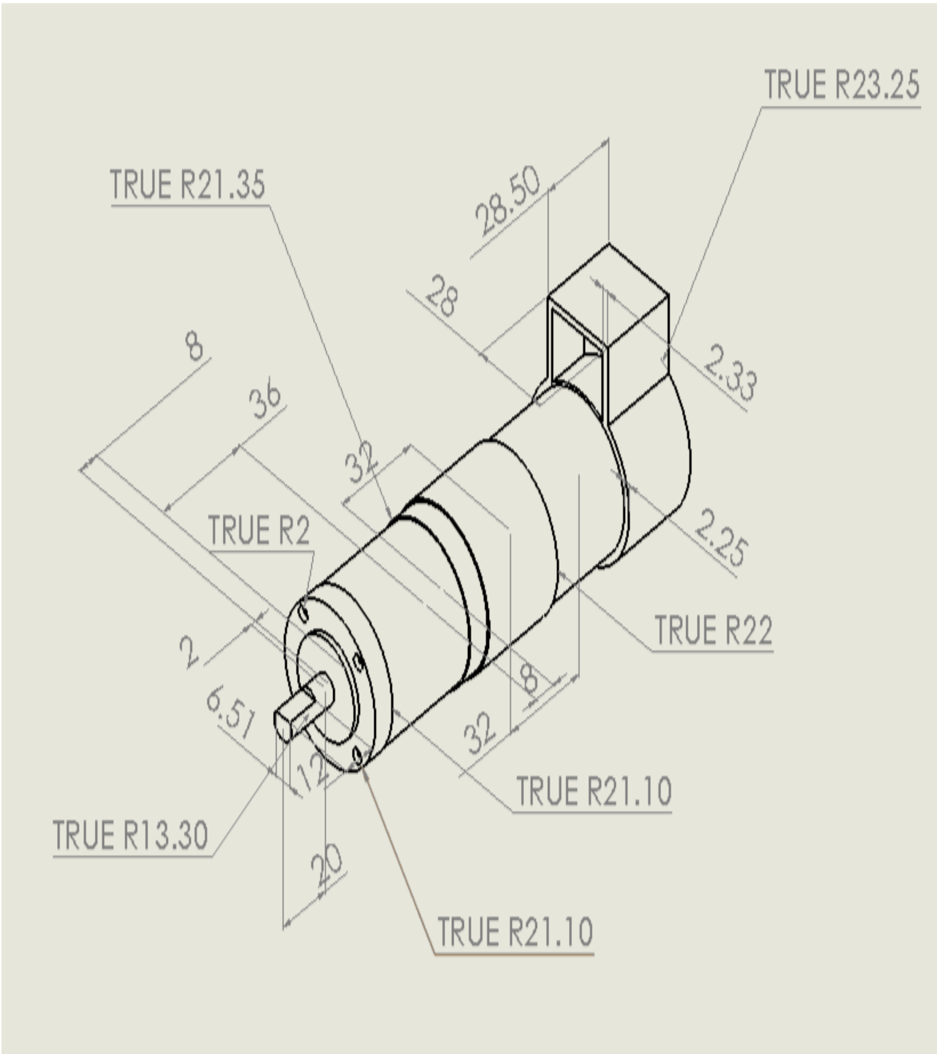

Figure 4.27: Dimensions of the motor

CHAPTER 5

THE ESSENTIAL COMPONENTS

5.1 FORCE SENSORS

The choice of a force sensor was finalized after much consideration of the requirements that was desired, the different types of sensors, their abilities, power requirement, sensitivity and drawbacks. The different benefits and delimitations of the force sensors were analysed and it was eventually chosen due to its small size, low cost and ability to withstand greater shock. A force sensor is shown in figure 5.1.

Owing to its high sensitivity, even the minute forces of intent will not be left undetected. They are resistive sensors, such as strain gauges, but they rely on different working principles. In fact, strain gauges are based on the variation of length and width of the conductor, while force sensing resistor is based on the variation of conductivity of the sensor itself. There are of course also mechanical deformations but they produce different effects.

Figure 5.1: Force Sensor

5.2 THE SERVO MOTOR

The motor that met the incumbent requirements was found to be Mega torque DC planetary geared encoder servo motor, 350W, 25rpm, 18V DC, 650Kgcm (figure 5.2). The Mega Torque Planetary Encoder DC Geared Motor with Japanese Mabuchi motor RS-775WC as base motor of 25RPM is a unique system which enables you to get the stall torque of the motor even while using the motor at lower RPM. For RPM starting from 0 to maximum rpm possible as per gear box ratio, it's possible to achieve the stall torque of the motor.

Figure 5.2: Motor

Using a simple DC motor, it is not possible to achieve desired torque at lower speeds because as variations happen in the input provided to the motor drive the output power is reduced. However, the Mega Torque Planetary Encoder DC Geared Motor along with the DC servo drive the encoder feedback is a unique system which will allow to achieve maximum rated torque at lower speeds along with perfect position and multimotor co-ordination. 42mm diameter planetary gearbox gives breaking torque upto 200kgcm. Rated torque of this motor is 25Kgcm at rated 600RPM. This motor has 500 Line optical encoder. This being a Quad Encoder requires 2000 Pulses Per Revolution of the base motor. Gear ratio is 1:625.

The block diagram of required electrical circuit is shown in figure 5.3 below.

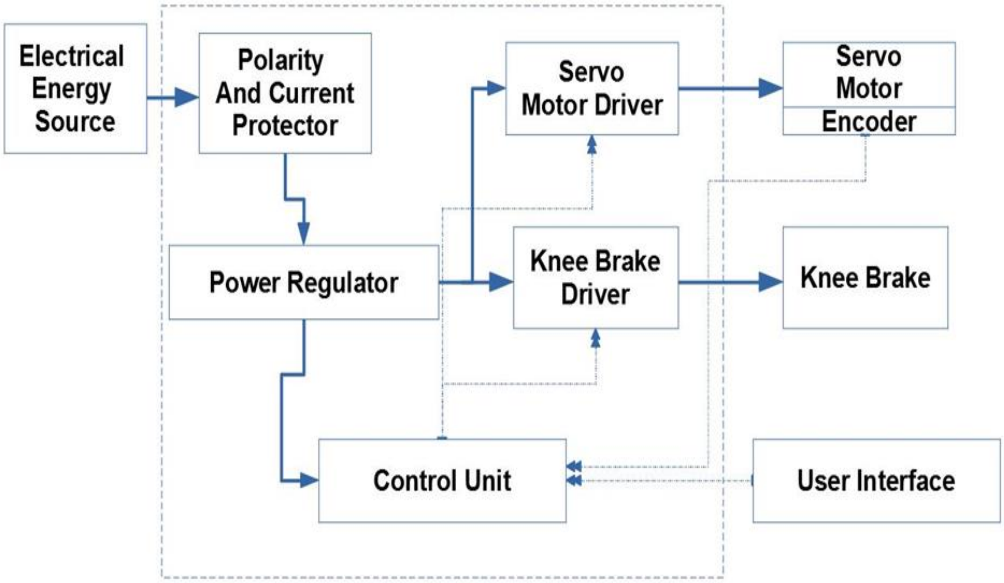

Figure 5.3: Block diagram of the electrical circuit.

This motor is perfect for our purpose. It gives a very fine setting to achieve required speed control using the high number of counts which are available with the coupled encoder. Also with the help of bevel gear assembly power flow can be shifted to 90 degree. DC servo motor driver has the specifications of 40V, 20A W/T step/direction input.The motor driver is shown in figure 5.4. The position of the DC servo motor can be controlled by a STEP/PULSE and DIRECTION digital interface similar to stepper motors. The PULSE/STEP, DIRECTION inputs are optically isolated. This drive is fully compatible with RMCS-2002, RMCS-2003 and RMCS-2004 motors. This motor driver ensures smooth and quiet operation at all speeds and zero backlash in DC Servo Motor performance.

Figure 5.4: Motor driver

5.3 LITHIUM POLYMER BATTERY

The battery used to power the exoskeleton model is Skycell 22.2 V 220000mAh Lithium-polymer Rechargeable battery. The battery is shown in figure 5.5. It can give great instantaneous discharge current up to 550A. it is very light weight and small size compared to Ni-Cd, Ni-MH and Lead acid batteries. It has a very long life without losing its charging capacity. It's life for full charging capacity can be up to one thousand charge cycles. This battery contains six lithium polymer 3.7V 22000mAh cells in series. This battery is categorized in low maintenance and its maximum charging current is 1A.

Figure 5.5: The battery

As our battery needs to be charged without fail, finding a proper battery charging device was the next priority. For this purpose, the most suitable charger was IMAX B6-AC CHARGER/DISCHARGER (1-6 CELLS). This device is 100~240v AC or 12V DC input. This charger is microprocessor controlled. It has delta-peak sensitivity to determine whether the battery is fully charged or not. There is individual cell balancing and this device is capable of charging Li-ion, LiPo and LiFe batteries along with Ni-Cd and NiMH batteries. It has large range of charge currents. It only allows safe storage currents. It is provided with time limit function and input voltage monitoring.

5.4 NI MYRIO

The controller used for programming the exoskeleton is NI myRIO 1900 (figure 5.6). It is embedded and reconfigurable. It is a real-time evaluation board developed by National

Instruments. It runs on LabVIEW. It was found to be a suitable option as a controller for the exoskeleton model.

This device can implement multiple design concepts with one reconfigurable I/O (RIO) device. This features input and output on both sides of the device in the form of MXP and MSP connectors and it includes 10 analog inputs, six analog outputs, 40 digital I/O lines, WiFi, LEDs, a push button, an onboard accelerometer, a Xilinx FPGA, and a dual-core ARM Cortex-A9 processor. The programming of the myRIO-1900 is done using LabVIEW or C. This WiFi-enabled version allows for fast and easy integration into remote embedded applications.

Figure 5.6: NI myRIO

The NI myRIO-1900 provides analog input (AI), analog output (AO), digital input and output (DIO), audio, and power output in a compact embedded device. The NI myRIO-1900 connects to a host computer over USB. The following figure 5.7 shows the arrangement and functions of NI myRIO-1900 components.

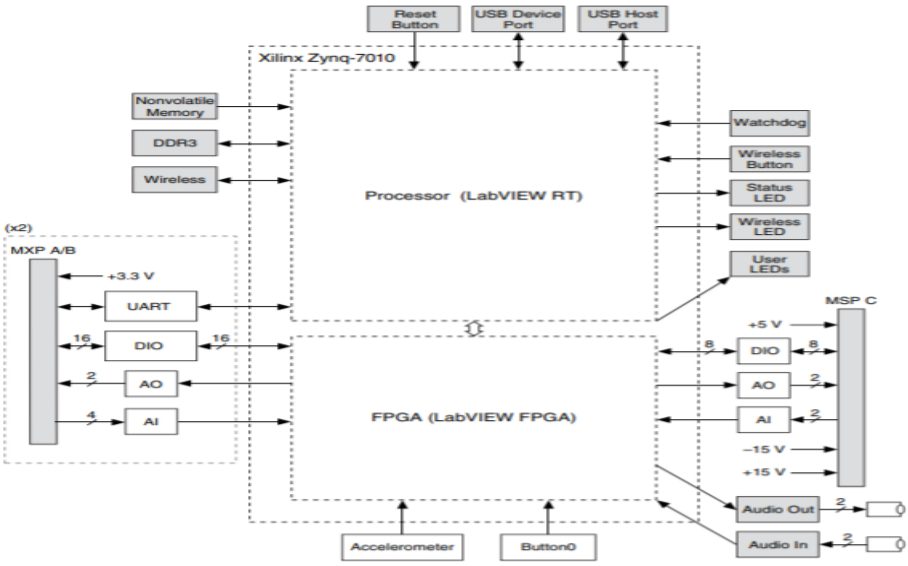

Figure 5.7: Components of myRIO

NI myRIO-1900 Expansion Port (MXP) connectors A and B carry identical sets of signals. The signals are distinguished in software by the connector name, as in Connector A/DIO1 and Connector B/DIO1. Refer to the software documentation for information about configuring and using signals. The following figure and table show the signals on MXP connectors A and B. Note that some pins carry secondary functions as well as primary functions.

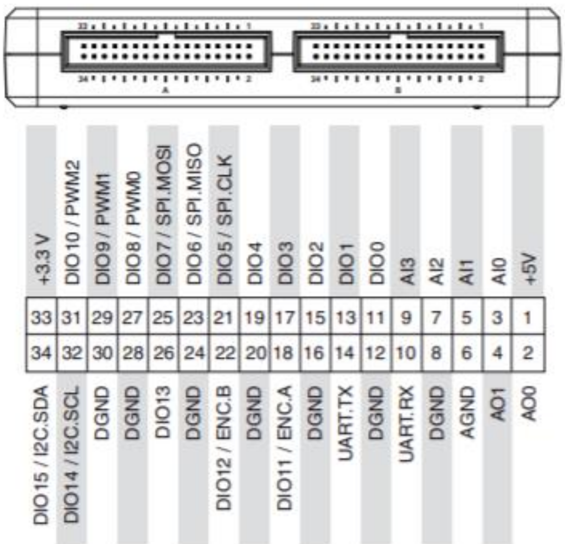

Figure 5.8: Signals on Connectors A and B

TABLE 5.1 : Signals on connectors Aand B

Signal Name	Reference	Direction	Description
+5V	DGND	Output	+5 V power output.
AI <0..3>	AGND	Input	0-5 V, referenced, single-ended analog input channels. Refer to the *Analog Input Channels* section for more information.
AO <0..1>	AGND	Output	0-5 V referenced, single-ended analog output. Refer to the *Analog Output Channels* section for more information.
AGND	N/A	N/A	Reference for analog input and output.
+3.3V	DGND	Output	+3.3 V power output.
DIO <0..15>	DGND	Input or Output	General-purpose digital lines with 3.3 V output, 3.3 V/5 V-compatible input. Refer to the *DIO Lines* section for more information.
UART.RX	DGND	Input	UART receive input. UART lines are electrically identical to DIO lines.
UART.TX	DGND	Output	UART transmit output. UART lines are electrically identical to DIO lines.
DGND	N/A	N/A	Reference for digital signals, +5 V, and +3.3 V.

The following figure 5.9 and table 5.2 show the signals on Mini System Port (MSP) connector C.

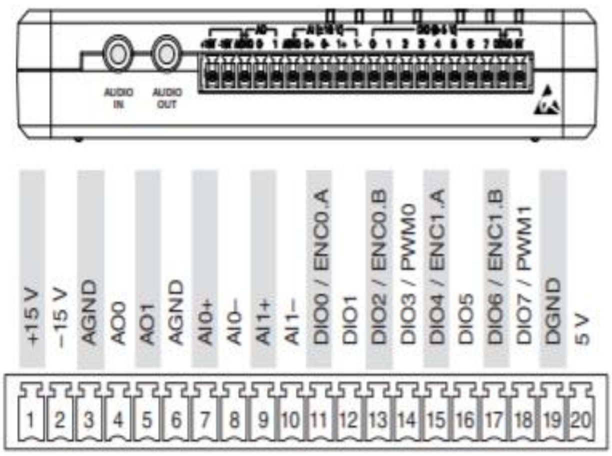

Figure 5.9: Signals on Connector C

Table 5.2: Signals on connector C

Signal Name	Reference	Direction	Description
+15V/-15V	AGND	Output	+15 V/-15 V power output.
AI0+/AI0-; AI1+/AI1-	AGND	Input	±10 V, differential analog input channels. Refer to the *Analog Input Channels* section for more information.
AO <0..1>	AGND	Output	±10 V referenced, single-ended analog output channels. Refer to the *Analog Output Channels* section for more information.
AGND	N/A	N/A	Reference for analog input and output and +15 V/-15 V power output.
+5V	DGND	Output	+5 V power output.
DIO <0..7>	DGND	Input or Output	General-purpose digital lines with 3.3 V output, 3.3 V/5 V-compatible input. Refer to the *DIO Lines* section for more information.
DGND	N/A	N/A	Reference for digital lines and +5 V power output.

For more information on the controller, refer to Appendix-B.

5.5 THE BACKPACK

A backpack is used to store the battery and other electronic components of the system including the controller and motor drives. This backpack is designed in the same way as a simple backpack with wider straps to equally distribute the total weight inside the bag so it won't feel too heavy. The bag is provided with an outlet from which comes out the power lines and other control lines to the motor, solenoid etc which is shown in figure 5.10. Using a simple backpack increases the ease of carrying the exoskeleton system around. The side profile of the bag is shown in figure 5.11.

Figure 5.10: The charging port at the side of the bag

Figure 5.11: A better view of the backpack

CHAPTER 6

EVALUATION OF THE DESIGN

It is observed clearly from the research gathered that rehabilitation robotics, is a field that is quite vast, even if it were to be narrowed down or focused on certain specific types of devices. To analyze the novel design in terms of their utility and conclude meaningful propositions of the future of the technologies used, they have to be broken down into different smaller categories and separately looked at.

These categories that decide the utility and meaningfulness of the design are interconnected with each other The following figure 6.1 shows the relationship of these categories with each other:

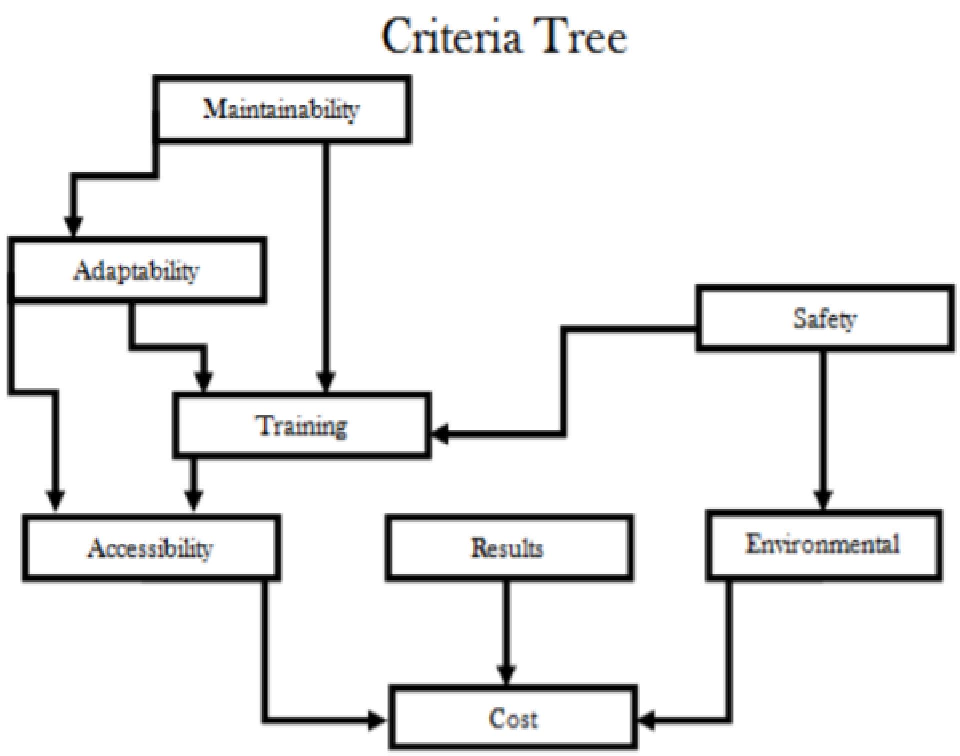

Figure 6.1: Criteria Tree showing the different criteria of evaluation

Based on the research, observations, current and past trends witnessed in the field, a list was made that should be enough for rating and comparing the design with the previous models. Any device can be analysed within each of the categories and then rated with a value from one to five. The goal of this is to have a way of looking at such devices on the same plane. The categories are as follows:

6.1 COST

Cost is a main criterion. The value of the device depends greatly on its cost because this in turn has an effect on how wide-spread an audience it could potentially reach. This category helps in identifying whether the device is attainable in large rehabilitation centres, or for normal average everyday people. Cost can also be a deciding factor for people depending on service providers. The market survey results are depicted in figure 6.2.

The design that is proposed meets this concern. The total expense in the complete production of the design is estimated to be around Rs. 80,000/- and can be sold within 1lakh. The existing models are all priced at figures greater than one lakh. Certainly, this proves to be a major advantage when compared to these models.

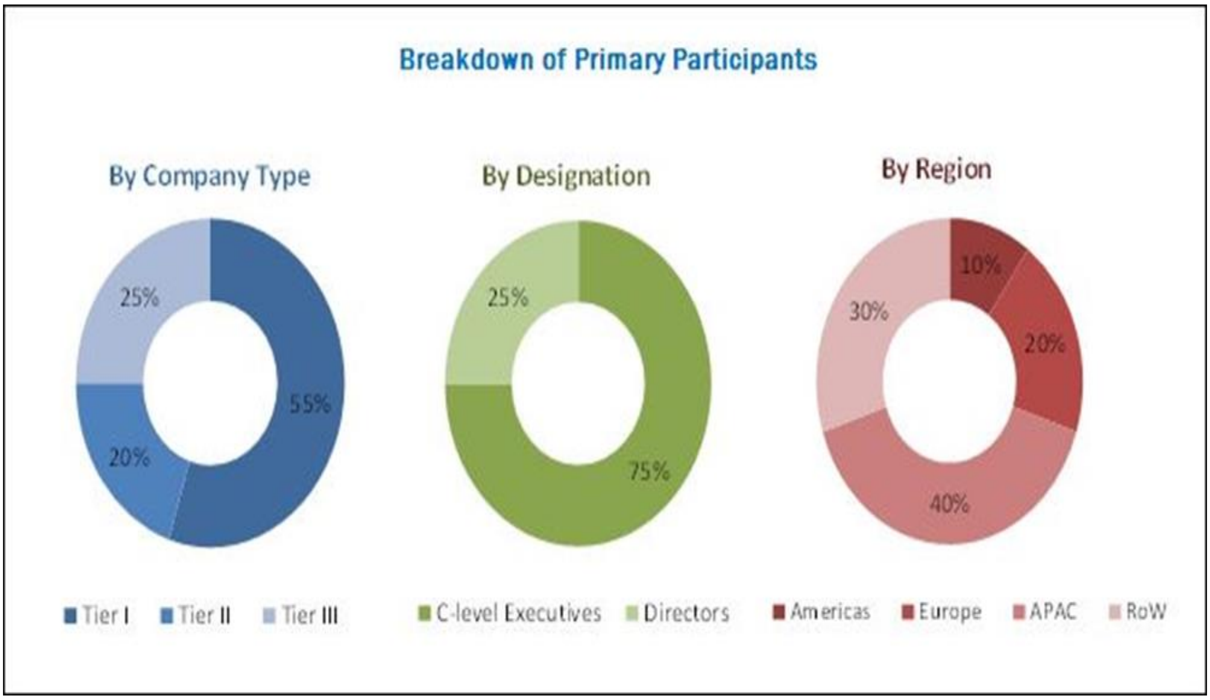

Figure 6.2: Market Survey

The exoskeleton market is also estimated to grow in the coming years to USD 2,810.5 Million by 2023, at a CAGR of 45.2% between 2017 and 2023, and a cost-effective, light-weight exoskeleton would surely captivate the markets.

6.2 ACCESIBILITY

Some rehabilitation devices can only be used in large rehabilitation centres, owing to the large size, maintenance required, high cost or trained personnel required for its operation. Yet not many areas have such facilities. Moreover, some centres do not possess or support certain devices, hence patients have to travel to specific locations so as to gain access to such devices. So how useful a device may be, can be really limited to number of patients, who require the device and who actually have proper access to it. A device that finds utility at one's home, every day, without any trained personnel has the higher probability of being used by those who can benefit from it.

The model that has been designed can be made use of everyday according to the wish and comfort of the wearer. There is no necessity that it has to be used in a certain large rehabilitation centre.

6.3 MAINTAINABILITY

Repair costs, usability outdoors, calibrations, power issues, etc. maintainability covers all of these and more. Clients would not want to use anything that malfunctions all the time and requires constant maintenance. The device will become more trouble than it's actually worth, and more costly. Some clients hope to be able to use the device in normal life activities. Here weather and power issues come into sight. Also, accessibility for maintenance becomes an issue, they will not want to, or can't, go weeks without the device while waiting on repairs or a replacement.

In terms of maintainability, the number of parts used is less. Since it is rechargeable, it can be used for longer terms. Furthermore, the device can be taken anywhere and the effect of weather will not be much of a factor as the electronics are housed in a backpack.

6.4 TRAINING

This category investigates the level of training required so that a device can be used properly. Some devices may require trained personnel which adds to the cost, and also limits their accessibility. Whereas some devices require very little training or none, that the user can pick up on their own. This category looks into these matters because they can affect other categories such as cost, accessibility, etc.

Initial training would be required for a person using this design as it would benefit them in the long run. Once they are able to walk on their own, they do not need the training anymore. This will also boost their morale and help them feel a little more confident as they pass through each stage successfully.

6.5 ADAPTABILITY

Another issue that is to be considered is adaptability, i.e. if a device is adaptable to multiple individuals, or very specifically designed for one person. Other concerns include whether or not the device can be made use of in a range of environments, specifically for children. Patients who are newly disabled or those in need of new prostheses, would often start the process by consulting with a medical professional before selecting a device.

The design that is proposed is able to meet this concern as it is made keeping the average height and BMI of an Indian person in mind.

6.6 SAFETY

The degree of safety for users, the weight, the material, reliability of the design, etc play a major role in this category. It determines the safety index of each device for users and people nearby as well. A number of aspects will be taken into account so that the safety rating can be determined.

The device that is newly designed will put the safety concern of the user as the most important of evaluation criteria as the very notion of creating a utility that is meant to assist a human winding up to be harmful instead generally questions the validity of the goal itself. Therefore, there will not be any compromise in the terms of safety with this design.

6.7 ENVIRONMENTAL CONCERNS

Mainly this category looks into the construction and disposal of such devices as well as the different materials used. This category will examine whether the device is environment friendly or not, in the terms of its construction and also its disposal. Since it is a form of recycling, the reusability of a device will also be taken into account to judge the matter.

Once the exoskeleton model is made from the said design it can be used throughout life. As such, its degree of reusability is high which in turn improves its degree of sustainability as well. Furthermore, it does not cause any sort of pollution or noise.

6.8 RESULTS

Patient relapse is basically the condition in which the patient loses the gained results and ends up back where he/she began. This category checks for this main condition and how long the clients must be assisted by this device before positive results can be observed. It determines how well the said device works.

Once the prototype is made based on the design, it will be tested on individuals with different degrees of paresis and conducting trials on a regular basis would give us a clear picture of the accomplishments the design has reached.

CHAPTER 7

RESULTS AND DISCUSSION

The analysis of the design was first conducted in Solidworks 2016 version. In order to conduct the analysis, the material properties of T6 were chosen. To include the weight of the subject, mass overriding was done for each part. Table 7.1 shows weight of each part, additional weight added and total weight.

Table 7.1: Details of component weight

Link(kg)	**Weight of link(kg)**	**Added weight(kg)**	**Total weight(kg)**
Thigh link	**1.13**	**8.87**	**10**
Shank link	**0.92**	**5.08**	**6**

7.1. MOTION ANALYSIS

Using motion analysis workbench, a rotary motor was fixed on pinion of the motor. Next the calculation was done after selecting the type of analysis, frame rate, accuracy, 3D contact resolution and integrated type (WSTIFF) was chosen. The gravity field was also applied to consider the effects of gravity on the model. The links that needs fixation were fixed. Constraints are applied between thigh link and shank link. Motor RPM is fixed as 25RPM just as the motor that is bought. Gravity was set to 9.81m/s^2. Then calculation was done. Figures 7.1, 7.2 and 7.3 shows the initial, intermediate and final positions of the exoskeleton respectively.

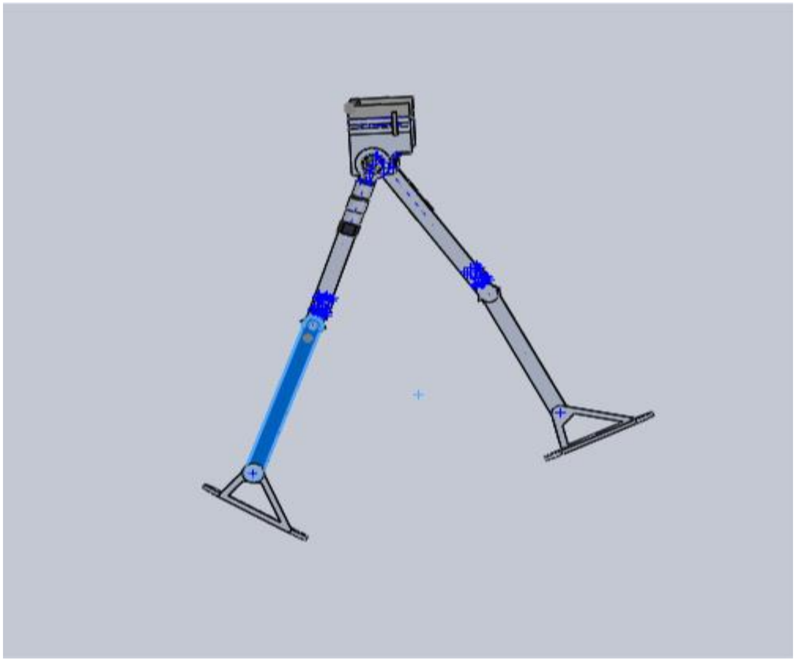

Figure 7.1: Initial Position

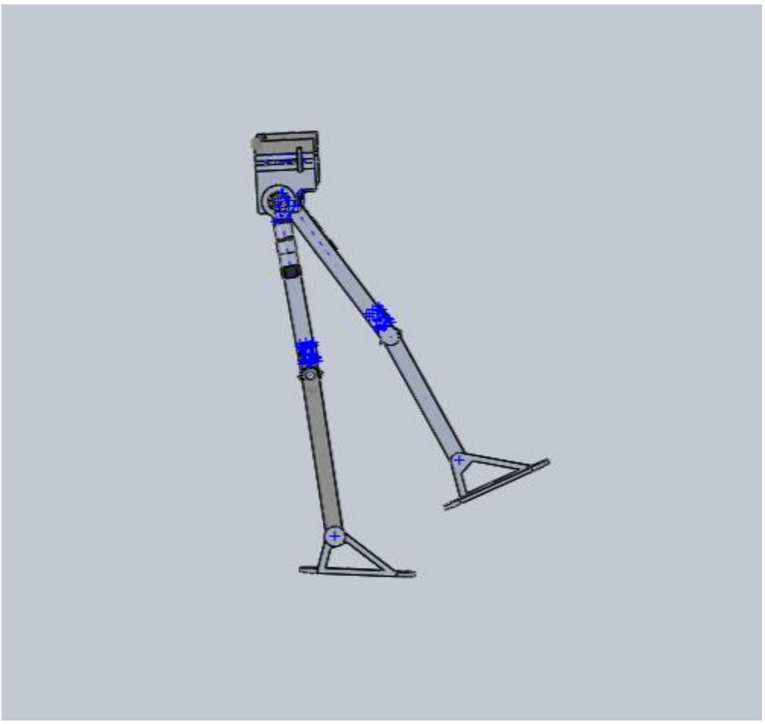

Figure 7.2: Intermediate Position

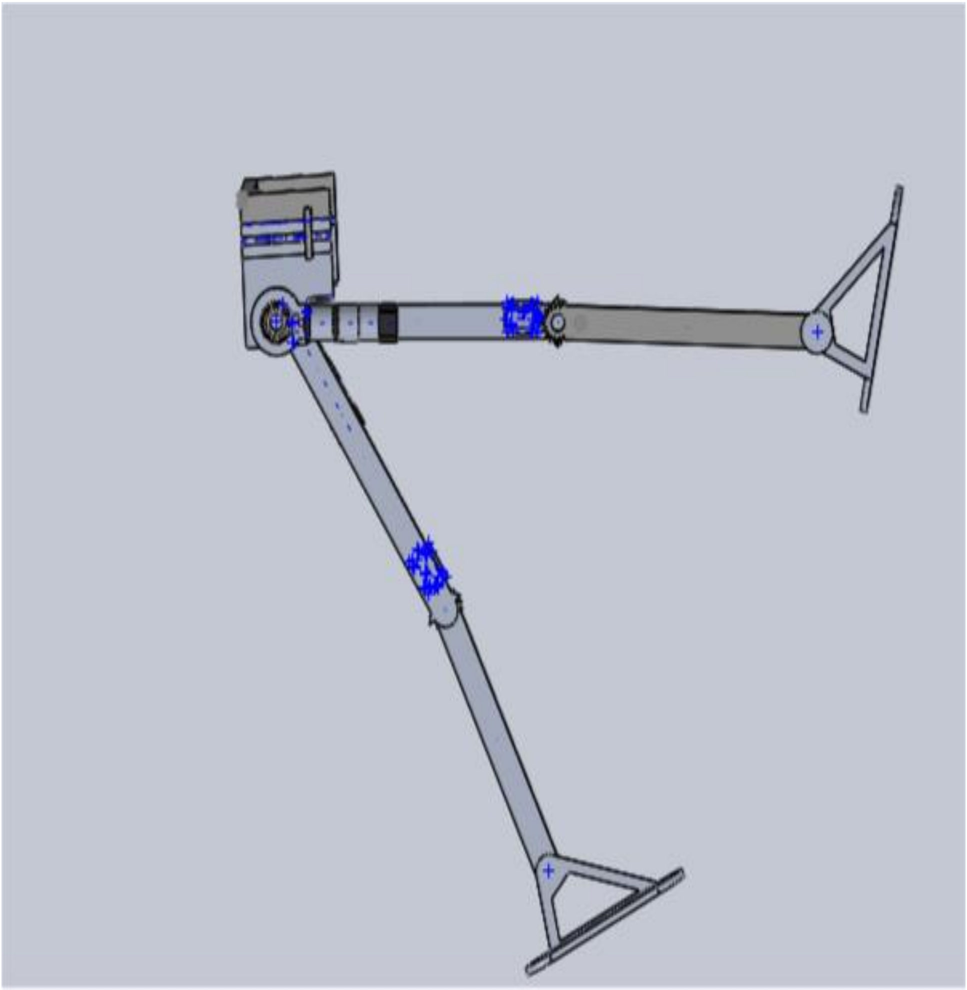

Figure 7.3: Final Position

7.2 TORQUE ANALYSIS

First the category type selected is force and subcategory is motor torque. Result component was opted as magnitude then motor was selected. A plot (figure 7.4) was obtained which shows time vs motor torque. From this graph the peak torque can be obtained. The values of time vs torque are as shown in table A1(Refer Appendix-A).

The result obtained showed the maximum torque as 63 Nm which is safe and within the motor limits. When the motor works under safe conditions, it is able to provide up to 650Kgcm or 63.74Nm. The current limit is also safe. Hence the gearset will be safe while operation. From the above result and from the motor characteristics the gear ratio of 25:12 is selected.

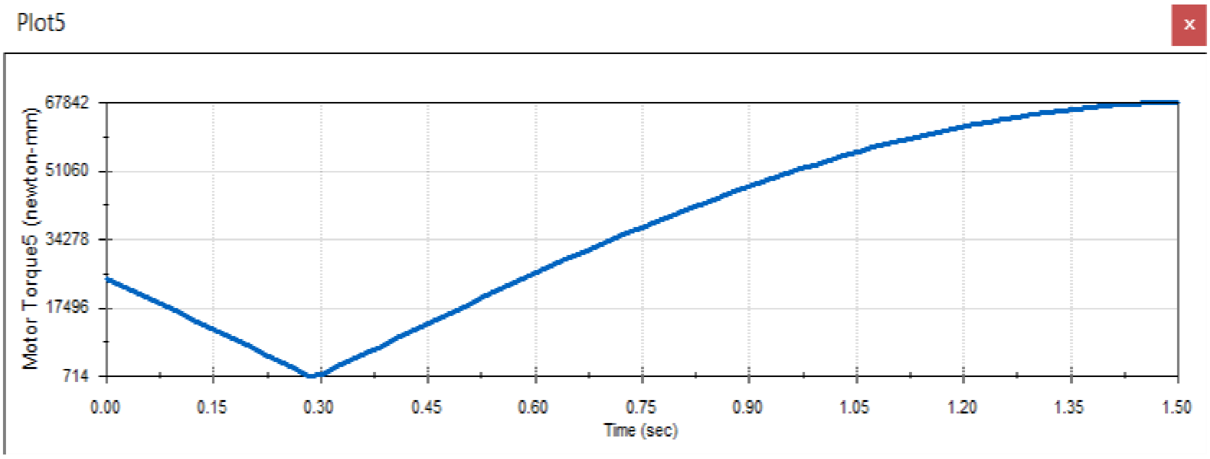

Figure 7.4: Torque Analysis Plot

7. 3 POWER ANALYSIS

For calculating the angular velocity, the above procedure was followed and the category chosen could be displacement/velocity/acceleration. The first power analysis plot is shown by figure 7.5.

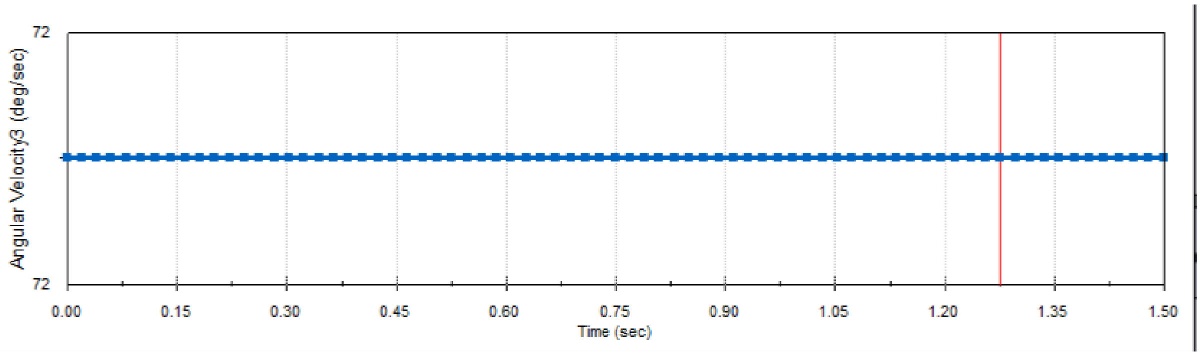

Figure 7.5: Power Analysis plot-1

The maximum angular velocity was obtained as 72 degree per second. Upon conversion it is obtained as 1.31 radians per second. The thigh link RPM was found as 12.

Maximum power was found as 86 W (figure 7.6). Due to gravity from initial position the value of power is negative until it reaches middle position which is zero power consumption. Then it rises to the maximum value at final position. The reason is the effect of gravity in the dynamic analysis. This change is shown in Table A2(Refer Appendix-A).

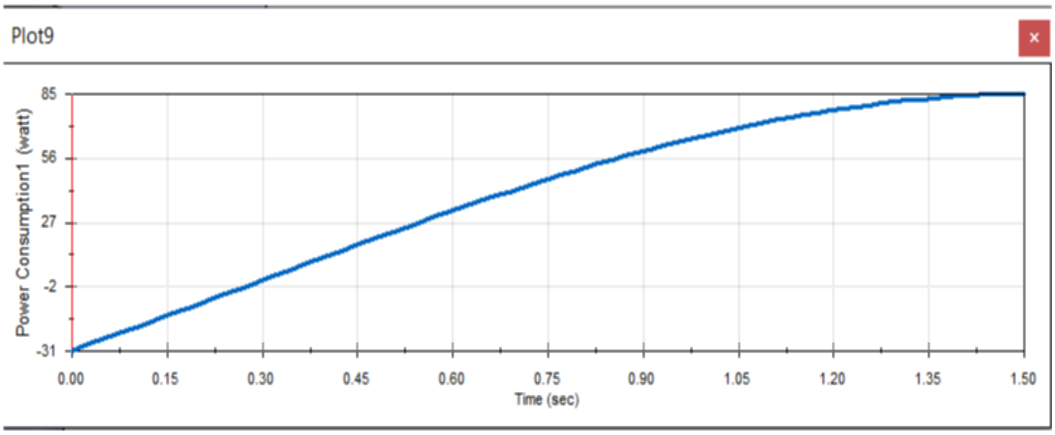

Figure 7.6: Power Analysis plot-2

7.4 STRUCTURAL ANALYSIS

In order to conduct the structural analysis, the following material properties of the chosen aluminium alloy were considered.

Elastic modulus= 69 GPa.

Poissons ratio= 0.33

Tensile strength= 240 MPa

Yield strength= 227.5 MPa

Mass density= 2700 kg /m2

The obtained stress- strain curve is shown in figure 7.7.

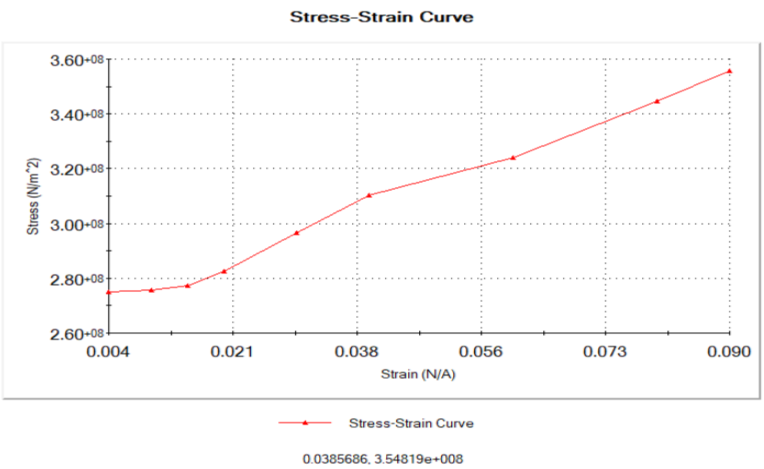

Figure 7.7: Stress vs Strain curve of the chosen alloy

The values of the graph correspond to table A3(refer Appendix A).

7.5 STATIC ANALYSIS

A new static simulation study was done. For this fixture Advisor option was used to select fixed geometries. External load was applied followed by suitable meshing. Figure 7.8 shows the initial state of analysis.

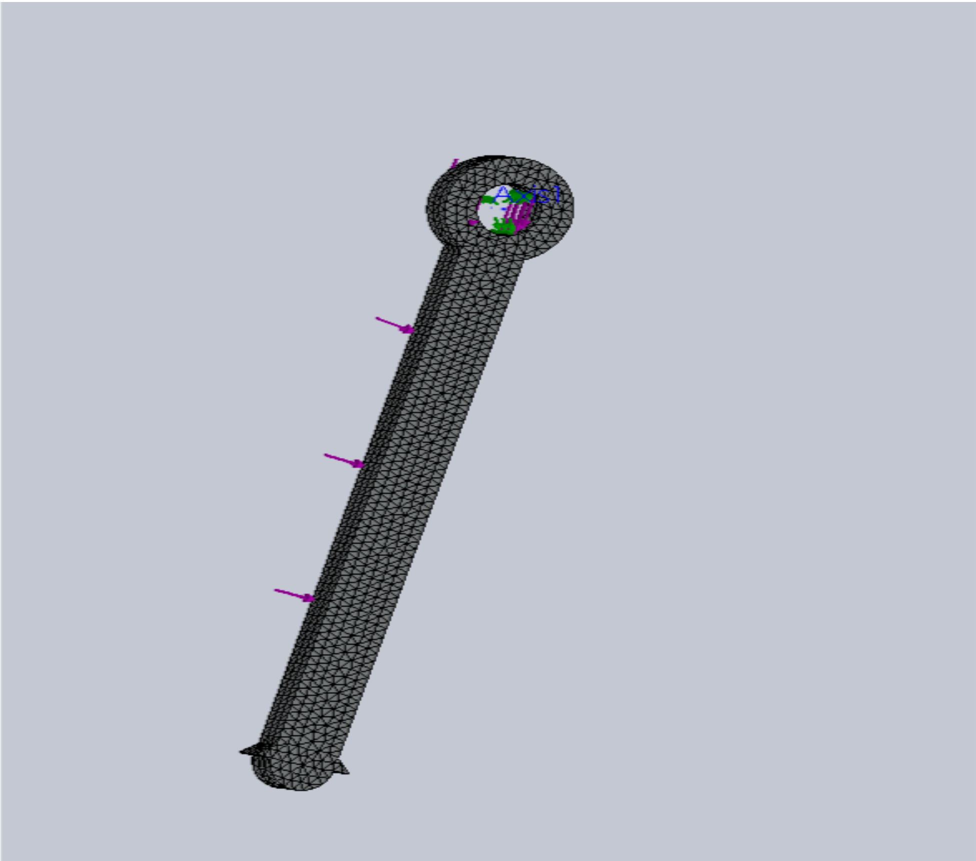

Figure 7.8: Initial State of analysis

After running the study, the results were obtained. Among which the most relevant ones were Von Mises stress results and factor of safety (figure 7.9).

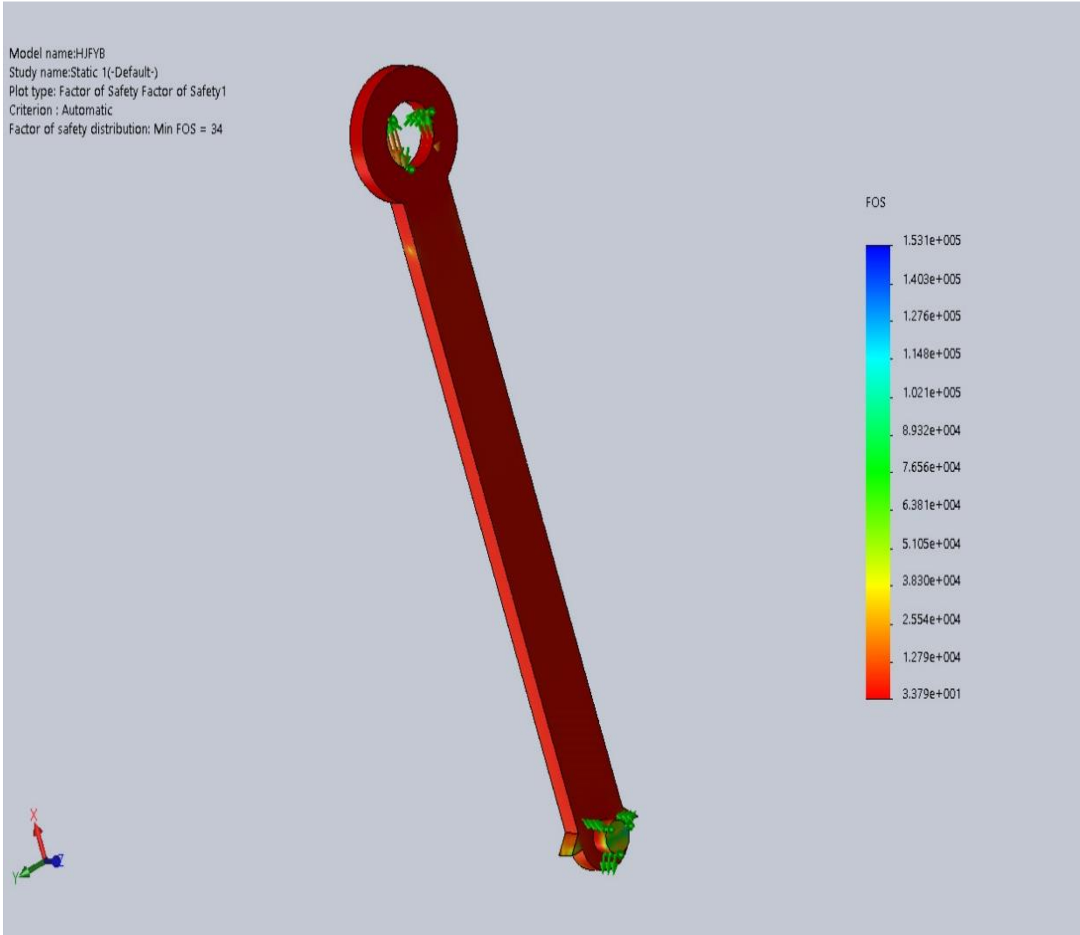

Figure 7.9: Checking for Factor of Safety

7.6 DESIGN STUDY

Optimizing the maximum material used was one of the top priorities of the project. Solidworks analysis was applied on the design to study this. In this variables are selected. Variables indicate the dimensions that are adjustable. In sensor types simulation data from previous analysis is given as input. Factor of safety is chosen from data quantity (figure 7.10). After many simulations and providing multiple increments by the software, a series of values satisfying safety limits are obtained. From this series the most optimized design is chosen by the software (figure 7.11).

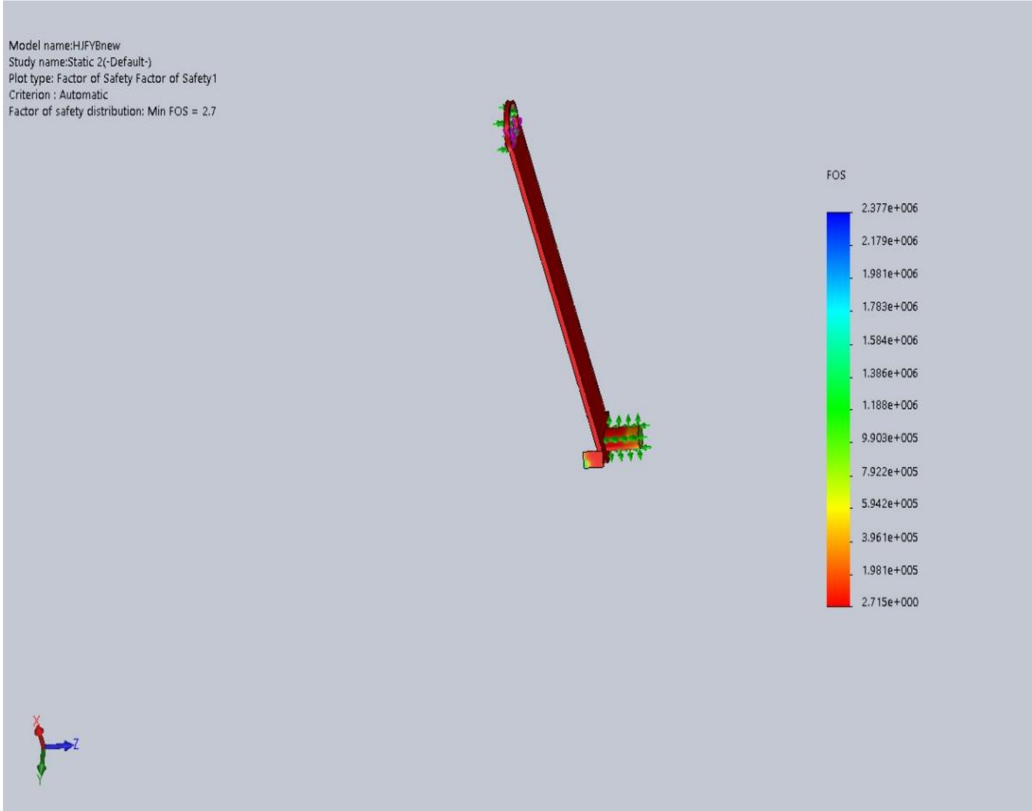

Figure 7.10: Finding the Factor of Safety

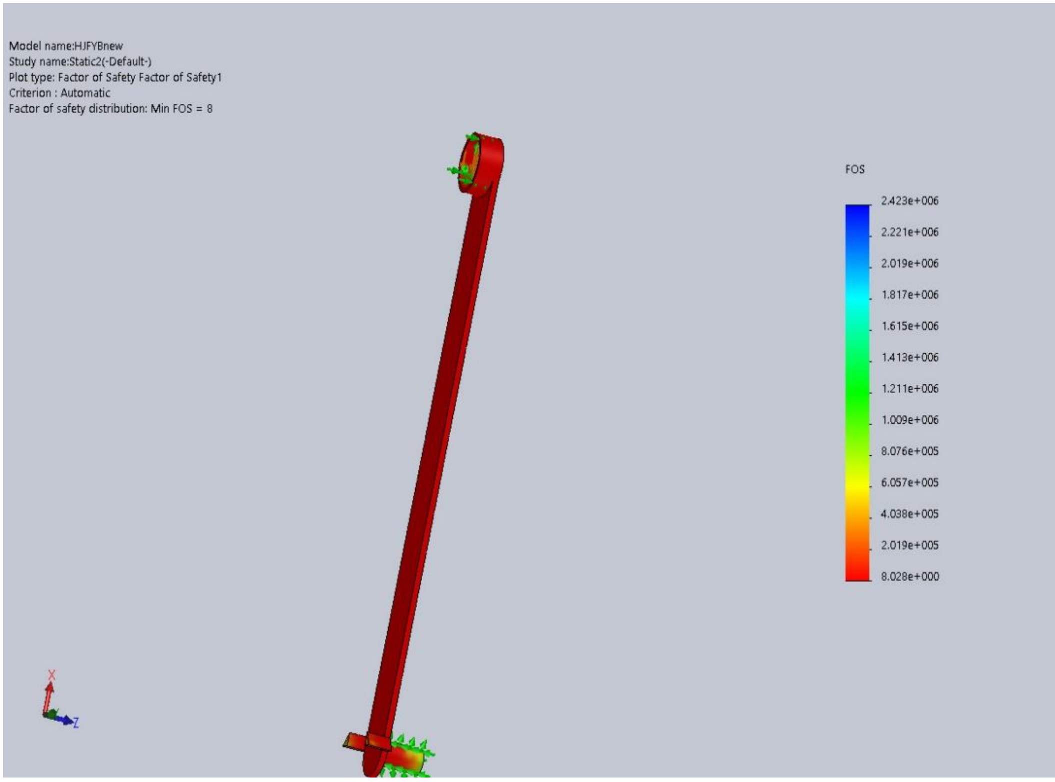

Figure 7.11: The chosen design with an FOS of 8

7.7 ANALYSIS ON ANSYS

An analysis using the ANSYS 15.0 with values in more proximity towards practical life was also conducted in order to check the viability of the system.

In this analysis, first the design was imported from SOLIDWORKS 2016 into this software. The majority of the analysis conducted in ANSYS was regarding the thigh link. This was due to the fact that most of the stress concentration and chances of failure occur at this point. In ANSYS, necessary material data was added. After fine meshing (figure 7.12), support data was provided. The support mentioned was cylindrical support. After specifying the bearing load as 1000N, the design was put under analysis. The result obtained was

Max equivalent Von Mises Stress= 9.1995 MPa

Tensile strength= 240 MPa, hence within safe limits.

Figure 7.13 shows the Von Mises Stress analysis on the thigh link.

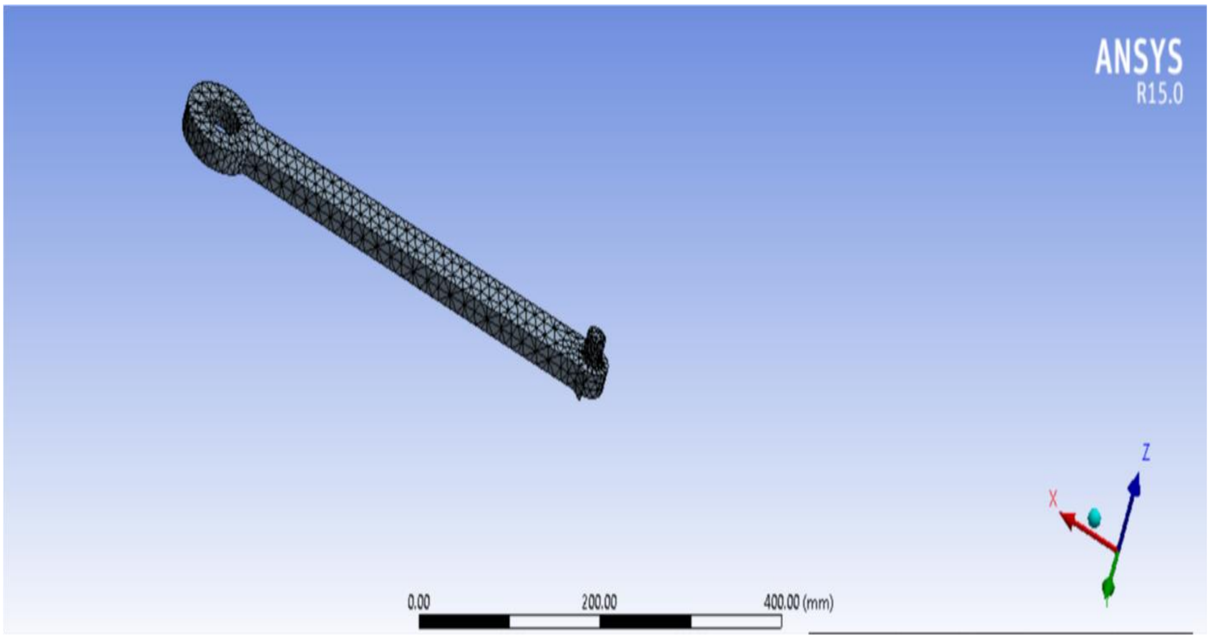

Figure 7.12: Meshing the thigh link

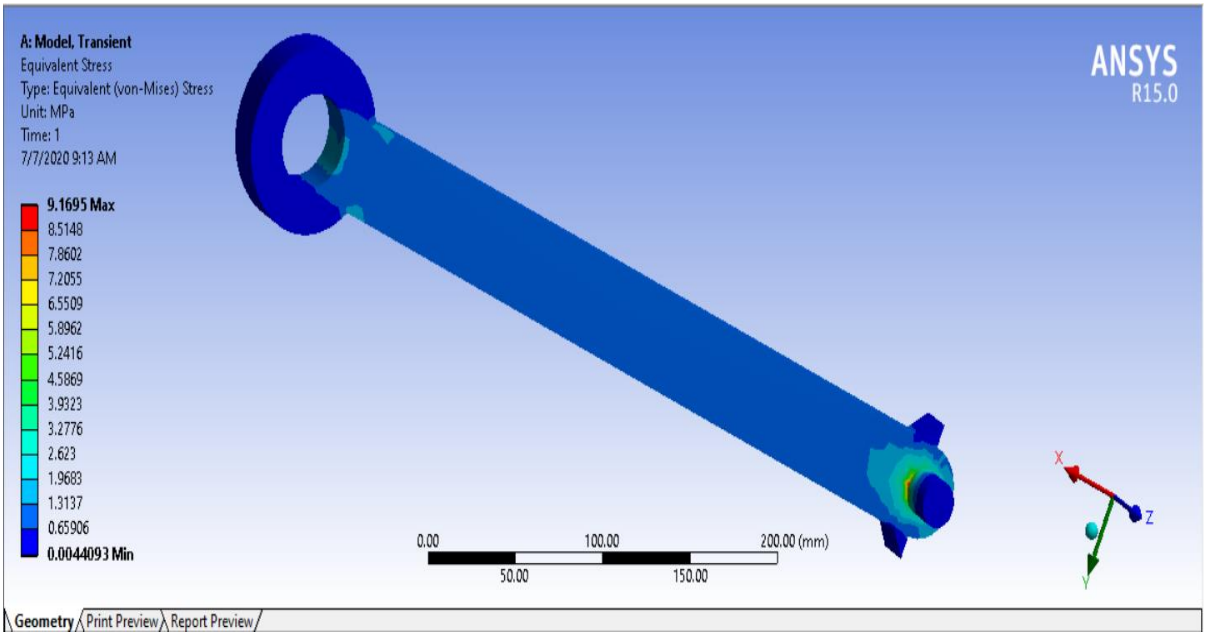

Figure 7.13: Von Mises Stress analysis on the thigh link

CHAPTER 8

FUTURE SCOPE

- As of now T6061 aluminum alloy is being used for fabrication. But carbon fiber is very light weight in nature and using it for developing the structure will help to make a low-profile structure. It also provides high strength, durability and high chemical resistance. The only limitation of using carbon fiber is to compromise the cost factor.

- Another major possibility is improvement of stability of the exoskeleton. For doing so, new methods should be incorporated and is presently under study.

- Energy can be harnessed from ankle joint which is presently wasted in this model. This energy stored from one phase can be utilized to support the next phase. This will increase the gait efficiency. One of the methods to do this is to attach a spring in the ankle joint base and use it to store the energy.

- Artificial intelligence can be made us of to detect the needs of the user and make the exoskeleton act according those needs. It should also be able to recognize the terrain and act according to it. For example, an exoskeleton moves differently when it comes to climbing stairs.

- The exoskeleton can also be made to adjust the gait speed automatically.

- Voice recognition can also be incorporated to activate various features according to requirements.

- The exoskeleton design can be broadened to make a full body exoskeleton thus not only helping people with lower limb disabilities. Its usage can be hence expanded to more disabled people.

- Exoskeleton system can be developed in a way that it is also able to support various medical features like an external pacemaker, ECG telemetry or a simple oxygen cylinder.

- This device can be extended to military applications by varying its endurance strength motor specification and battery etc. This is intended to increase the power of a normal military official to carry out difficult and heavy tasks.

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CHAPTER 9

CONCLUSION

Rehabilitation Robotics is an ever-expanding field as newer research leads to creation of better devices and technologies each year. Yet the general rehabilitation efforts to support paralysis patients presently are limited and primitive and wheelchairs, support devices etc are the commonly used alternatives. People, who have been at a loss of function in their limbs or those who are somehow unable to control them, find themselves insufficiently equipped to make their actions and their time worthwhile. Humans are just not the swiftest creatures on Earth, and most of us seem to be limited in the sense of the amount of weight that we can pick up and carry.

A novel design that shall set apart a way for the common individual to access a better standard of living even though he might be paralyzed or partially atrophic, the design opens the door to a new world of endless possibilities for them as it aims to be economic and easily accessible to anyone. Most of the exoskeleton available in the market way too expensive and for a still developing country like India, it is necessary to model an exoskeletal device that was both useful and cheap.

The model is successfully designed to meet the economic and accessibility constraints for any individual suffering from partial muscular atrophy. It won't weigh heavily on Indian citizens in terms of its price and its mechanism is simple and easy to adapt within a fast pace. Due to its simple structure and limited number of components, the frequent repair and maintenance of the exoskeleton is also not necessary.

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APPENDIX-A

TABLES FOR DESIGN CALCULATIONS

Table A1 -Values of motor torque v/s time plot

Time (sec)	Motor Torque5 (newton-mm)
0	24384.93
0.02027	22761.98
0.040541	21124.28
0.060811	19460
0.081081	17777.43
0.101351	16133.22
0.121622	14447.15
0.141892	12751.7
0.162162	11047.99
0.182432	9337.104
0.202703	7620.162
0.222973	5898.277
0.243243	4172.564
0.263514	2444.145
0.283784	714.1392

0.304054	**1016.33**
0.324324	**2746.139**
0.344595	**4474.167**
0.364865	**6199.291**
0.385135	**7920.394**
0.405405	**9636.358**
0.425676	**11346.07**
0.445946	**13048.42**
0.466216	**14742.3**
0.486486	**16426.62**
0.506757	**18100.29**
0.527027	**19762.2**
0.547297	**21411.3**
0.567568	**23046.5**
0.587838	**24666.76**
0.608108	**26271**
0.628378	**27858.21**
0.648649	**29427.34**
0.668919	**30977.37**
0.689189	**32507.31**
0.709459	**34016.16**
0.72973	**35502.93**
0.75	**36966.67**
0.77027	**38406.43**
0.790541	**39821.27**
0.810811	**41210.28**
0.831081	**42572.54**

0.851351	43907.19
0.871622	45213.34
0.891892	46490.16
0.912162	47736.82
0.932432	48952.51
0.952703	50136.44
0.972973	51287.84
0.993243	52405.96
1.013514	53490.08
1.033784	54539.49
1.054054	55553.52
1.074324	56531.51
1.094595	57472.82
1.114865	58376.84
1.135135	59242.98
1.155405	60070.69
1.175676	60859.42
1.195946	61608.67
1.216216	62317.95
1.236486	62986.79

Table A2- Values of power consumption v/s time plot

Time (sec)	Power Consumption1 (watt)
0.304054	1.277157
0.324324	3.4509
0.344595	5.622403
0.364865	7.790259
0.385135	9.953061
0.405405	12.1094
0.425676	14.25789
0.445946	16.39713
0.466216	18.52573
0.486486	20.6423
0.506757	22.74549
0.527027	24.83392
0.547297	26.90623
0.567568	28.96109
0.587838	30.99716
0.608108	33.01312
0.628378	35.00766
0.648649	36.97948
0.668919	38.92731
0.689189	40.84989
0.709459	42.74596
0.72973	44.6143

0.75	**46.45369**
0.77027	**48.26295**
0.790541	**50.04089**
0.810811	**51.78636**
0.831081	**53.49823**
0.851351	**55.1754**
0.871622	**56.81676**
0.891892	**58.42126**
0.912162	**59.98786**
0.932432	**61.51554**
0.952703	**63.00331**
0.972973	**64.4502**
0.993243	**65.85527**
1.013514	**67.21761**
1.033784	**68.53635**
1.054054	**69.81062**
1.074324	**71.03959**
1.094595	**72.22247**
1.114865	**73.3585**
1.135135	**74.44693**
1.155405	**75.48706**
1.175676	**76.47821**
1.195946	**77.41974**
1.216216	**78.31104**
1.236486	**79.15153**
1.256757	**79.94067**
1.277027	**80.67795**

1.297297	**81.36287**
1.317568	**81.99501**
1.337838	**82.57395**
1.358108	**83.09932**
1.378378	**83.57077**
1.398649	**83.988**
1.418919	**84.35074**
1.439189	**84.65875**
1.459459	**84.91183**
1.47973	**85.10982**
1.5	**85.25259**

Table A3- Values for stress-strain graph

Point	X	Y1 (Stress-Strain Curve)
1	0.004	2.75E+08
2	0.01	2.76E+08
3	0.015	2.77E+08
4	0.02	2.83E+08
5	0.03	2.96E+08
6	0.04	3.10E+08
7	0.06	3.24E+08
8	0.08	3.45E+08
9	0.09	3.56E+08

APPENDIX-B

SPECIFICATIONS OF NI myRIO

The following are the specifications typical to the controller at operating temperatures between 0 to 40 ^{o}C.

Processor:

Processor type ....Xilinx Z-7010

Processor speed...667 MHz

Processor cores 2

Memory:

Nonvolatile memory ....512 MB

DDR3 memory...256 MB

DDR3 clock frequency ....533 MHz

DDR3 data bus width................................16 bits

FPGA:

FPGA type ....Xilinx Z-7010

Wireless Characteristics:

Radio mode ....IEEE 802.11 b,g,n

Frequency band...ISM 2.4 GHz

Channel width ....20 MHz

Channels .... USA 1 to 11, International 1 to 13

TX power... +10 dBm max (10 mW)

Outdoor range .... Up to 150 m (line of sight)

Antenna directivity .... Omnidirectional

Security.. WPA, WPA2, WPA2-Enterprise

USB Ports:

USB host port .... USB 2.0 Hi-Speed

USB device port.. USB 2.0 Hi-Speed

Analog Inputs:

Aggregate sample rate .... 500 kS/s

Resolution... 12 bits

Overvoltage protection .... ±16 V

MXP connectors

Configuration.. Four single-ended channels per connector

Input impedance .... >500 kΩ acquiring at 500 kS/s

1 MΩ powered on and idle

4.7 kΩ powered off

Recommended source impedance .... 3 kΩ or less

Nominal range .... 0 V to +5 V

Absolute accuracy..................................... ±50 mV

Bandwidth... >300 kHz

MSP connector

Configuration... Two differential channels

Input impedance .... Up to 100 nA leakage powered on;

4.7 kΩ powered off

Nominal range .... ±10 V

Working voltage

(signal + common mode).......................... ±10 V of AGND

Absolute accuracy.................................... ±200 mV

Bandwidth.. 20 kHz minimum, >50 kHz typical

Audio input

Configuration... One stereo input consisting of two AC-coupled, single-ended channels

Input impedance .... 10 kΩ at DC

Nominal range .... ±2.5 V

Bandwidth.. 2 Hz to >20 kHz

Analog Output:

Aggregate maximum update rates

All AO channels on MXP connectors.......345 kS/s

All AO channels on MSP connector

and audio output channels.........................345 kS/s

Resolution ....12 bits

Overload protection ....±16 V

Startup voltage ....0 V after FPGA initialization

MXP connectors

Configuration ....Two single-ended channels per connector

Range ....0 V to +5 V

Absolute accuracy.....................................50 mV

Current drive ....3 mA

Slew rate ....0.3 V/µs

MSP connector

Configuration ....Two single-ended channels

Range ....±10 V

Absolute accuracy.....................................±200 mV

Current drive ....2 mA

Slew rate ....2 V/µs

Audio output

Configuration ....One stereo output consisting of
two AC-coupled, single-ended channels

Output impedance ....100 Ω in series with 22 µF

Bandwidth...70 Hz to >50 kHz into 32 Ω load;
2 Hz to >50 kHz into high-impedance load

Digital I/O:

Number of lines

MXP connectors ....2 ports of 16 DIO lines (one port per connector);
1 UART.RX and 1 UART.TX line per connector

MSP connector...1 port of 8 DIO lines

Direction control ....Each DIO line individually programmable as
input or output

Logic level ....5 V compatible LVTTL input; 3.3 V LVTTL
output

Input logic levels

Input low voltage, VIL .... 0 V min; 0.8 V max

Input high voltage, VIH .... 2.0 V min; 5.25 V max

Output logic levels

Output high voltage, VOH

sourcing 4 mA .... 2.4 V min; 3.465 V max

Output low voltage, VOL

sinking 4 mA .... 0 V min; 0.4 V max

Minimum pulse width...................................... 20 ns

Maximum frequencies for secondary digital functions

SPI .... 4 MHz

PWM... 100 kHz

Quadrature encoder input .... 100 kHz

I2C.. 400 kHz

UART lines

Maximum baud rate.................................. 230,400 bps

Data bits.. 5, 6, 7, 8

Stop bits 1, 2

Parity... Odd, Even, Mark, Space

Flow control.. XON/XOFF

Power Output:

+5 V power output

Output voltage .... 4.75 V to 5.25 V

Maximum current on each connector .... 100 mA

+3.3 V power output

Output voltage .... 3.0 V to 3.6 V

Maximum current on each connector .... 150 mA

+15 power output

Output voltage...+15 V to +16 V

Maximum current ....32 mA (16 mA during startup)

-15 V power output

Output voltage...-15 V to -16 V

Maximum current ....32 mA (16 mA during startup)

Maximum combined power from +15 V

and -15 V power output ....500 mW

Power Requirements:

NI myRIO-1900 requires a power supply connected to the power connector.

Power supply voltage range..............................6 to 16 VDC

Maximum power consumption ....14 W

Typical idle power consumption.......................2.6 W

Physical Characteristics:

Weight…………………………………………193g